THE

QUARTERLY JOURNAL

OF THE

GEOLOGICAL SOCIETY OF LONDON.

EDITED BY

THE PERMANENT SECRETARY OF THE GEOLOGICAL SOCIETY.

Quod si cui mortalium cordi et curæ sit non tantum inventis hærere, atque iis uti, sed ad ulteriora penetrare; atque non disputando adversarium, sed opere naturam vincere; denique non belle et probabiliter opinari, sed certo et ostensive scire; tales, tanquam veri scientiarum filii, nobis (si videbitur) se adjungant —*Novum Organum*, *Præfatio*.

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MCMXXIII.

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Dates of Issue of the Quarterly Journal for 1923.

No. 313—April 11th, 1923.
No. 314—July 6th, 1923.
No. 315—September 22nd, 1923.
No. 316—December 29th, 1923.

Erratum.

Footnote 1, p. 13. *For* 'post-Miocene', *read* 'Miocene or post-Miocene'.

PROCEEDINGS

OF THE

GEOLOGICAL SOCIETY OF LONDON.

SESSION 1922–23.

November 8th, 1922.

Prof. A. C. Seward, Sc.D., F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The Names of certain Fellows of the Society were read out for the second time, in conformity with the Bye Laws, Sect. VI, Art. 5, in consequence of the Non-Payment of the Arrears of their Annual Contributions.

The following communications were read:—

1. 'The Earthquake of 7th August, 1895, in Northern Italy.' By Richard Dixon Oldham, F.R.S., V.P.G.S.

2. 'The Pamir Earthquake of 18th February, 1911.' By Richard Dixon Oldham, F.R.S., V.P.G.S.

3. 'The Geology of Sierra Leone.' By Frank Dixey, D.Sc., F.G.S. (Read by Dr. H. H. Thomas, M.A., V.P.G.S.)

Mr. R. D. Oldham exhibited lantern-slides in illustration of his papers; and lantern-slides and microscope-slides were exhibited in illustration of Mr. Dixey's paper.

November 22nd, 1922.

Prof. A. C. Seward, Sc.D., F.R.S., President, in the Chair.

Thomas Wyatt Bagshawe, the Grove House, Dunstable (Bedfordshire); Arthur Lennox Coulson, M.Sc., Finchley, 10 King

Street, Elsternwick, Victoria (Australia); Evan Llewelyn Davies, B.Sc., Tregenna, Clydach (Glamorgan); James Johnstone, B.A., M.B., F.R.C.S., 90 King's Road, Richmond (Surrey); George Mitchell, M.Inst.C.E., 41½ Union Street, Aberdeen; the Rev. Charles Overy, St. Frideswide's Vicarage, Oxford; William Poxon, Southgate View, Clowne, near Chesterfield; George Norman Scott, M.Sc., H.M. Inspector of Mines, 22 Richmond Road, Handsworth, Birmingham; James Clark Templeton, B.Sc., c/o the Bitumen Company, Gjorgičeva Ul. 2/II, Zagreb (Yugoslavia); and Wilfrid Seymour Walker, c/o Strick, Scott Ltd., Mohammerah (Persia), were elected Fellows of the Society.

The List of Donations to the Library was read.

Prof. Arthur Stanley Eddington, M.A., F.R.S., Pres.R.A.S., then proceeded to deliver a lecture on The Borderland of Astronomy and Geology. He considered first, in reference to rival hypotheses as to the origin of the Earth and the solar system, the general evolution of the stellar universe. The trend of modern astronomy is against the view that luminous stars are being formed by collisions of extinct stars (unless very exceptionally); the stars now observed have systematic relations one to the other, apparently indicating that they have been formed as the result of a single evolutionary process sweeping across the primordial matter. Collisions, in any case, would be extremely rare, since dynamical arguments indicate that extinct stars cannot greatly outnumber the observed luminous stars. Whether the original matter was gaseous or meteoric, it must have become entirely gaseous at a very early stage in the formation of a star: this is inferred from the fact that the masses of stars differ very little one from the other, and agree numerically with a certain critical mass, predicted theoretically for a sphere of gas, but unexplained if the star consisted of a swarm of meteorites. It is supposed that radiation-pressure was instrumental in breaking up the original matter into separate stars. These considerations favour the nebular hypothesis; but, if we accept Jeans's suggestion that the solar system is an exceptional formation, and that undisturbed stars cannot give birth to a planetary system, the argument is less cogent, since it refers only to stars developing normally. Astronomy now demands a great enlargement of Lord Kelvin's time-scale for the age of the sun; the most direct evidence is obtained from Cepheid variables, which are found to be developing at only 1/500 of the rate which Kelvin's hypothesis assumed. The sun must at one time have given out from 20 to 50 times as much heat as it emits now; but it is uncertain whether any geological strata go back to an epoch when the sun was sensibly hotter than now. Darwin's views on tidal evolution and the origin of the earth-moon system seem to have held their own against all criticism. The present rate of lengthening of the day (deduced from ancient eclipses) is about 1 minute in 6 million years; it

is, therefore, difficult to date the birth of the moon later than 1000 million years ago. There seems to be no objection to the postulate that the Earth had a cool solid crust at the time of the catastrophe, if that would explain geological observations; the Pacific Ocean may be the depression which was left, and may have received the waters which formerly covered most of the Earth. The dissipation of energy by the tides occurs chiefly in the land-locked shallow seas, G. I. Taylor having shown that the Irish Sea alone accounts for 1/50 of the whole amount. The brake on the Earth's rotation is thus a surface-brake; and the hypothesis suggests itself that there may be a slip of the outer crust over the interior at the 'zone of weakness'. If the slip is irregular, this would help to explain certain astronomical observations of irregularities in the longitudes of the moon, sun, and planets. It might even be the cause of the motion of the magnetic poles. The brake, being applied irregularly over the surface, would also tend to crumple the crust. The postulated looseness of the crust might also permit the North Pole to move about over the surface; but exceedingly long periods of time would be required, since there is no systematic tendency of the crust to move in latitude.

Dr. J. W. Evans, Prof. W. J. Sollas, Mr. R. D. Oldham, Dr. G. T. Prior, and the President having made certain observations and queries, to which the Lecturer replied, a cordial vote of thanks was unanimously accorded to him by the Fellows present.

December 6th, 1922.

Prof. A. C. Seward, Sc.D., F.R.S., President, and afterwards Mr. R. D. Oldham, F.R.S., Vice-President, in the Chair.

John Rickman Bourchier, Furze Reeds, Midhurst (Sussex); Charles Henry James Clayton, M.B.E., M.Inst.C.E., 53 Carlton Avenue, Dulwich, S.E. 21; William James Cousins, 2 Dorlcote Road, Wandsworth, S.W. 18; Leslie Reginald Cox, B.A., Assistant in the Department of Geology, British Museum (Natural History), 95 Mattison Road, Harringay, N. 4; Reginald Gordon Doyle, F.C.S., The Larches, 28 Newlands Park, S.E. 26; David Gibby, B.Sc., Glyn Llewellyn, Clynderwen (Pembrokeshire); Harry Cecil Haworth, B.Sc., 82 Leamington Road, Blackburn (Lancashire); George Arthur Hughes, 47 Thornhill Square, N. 1; Herbert Stanley Hunter, Thornton House, Hartburn, near Morpeth (Northumberland); Agnes Irene McDonald, M.Sc., Demonstrator in Geology at Bedford College, 103 Belgrave Road, S.W. 1; William Edward Frank Macmillan, 42 Onslow Square, S.W. 7; Sidney Leonard Mainprize, Wydale, St. John's Avenue, Bridlington (Yorkshire); Leslie Hamilton Ower, Government Geologist, Belize (British

Honduras); the Hon. Hubert Lister Parker, B.A., Nether Worton House, Steeple Aston (Oxfordshire); George Henry Plowman, Boxmoor Road, Highfield Road, Southampton; Charles Murray Pollock, B.A., Harefield, Chaucer Road, Cambridge; George Scotland Sweeting, Imperial College of Science & Technology, and 38 Pulborough Road, Wimbledon Park Road, S.W. 18; and John Walker Walton, L.D.S., Tower House, 16 Manor Road, Folkestone, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'Geological Investigations in the Falkland Islands.' By Herbert Arthur Baker, D.Sc., D.I.C., F.G.S.

2. 'On a Collection of Fossil Plants from the Falkland Islands.' By Albert Charles Seward, Sc.D., F.R.S., Pres.G.S., and John Walton, B.A.

Rock-specimens, fossils, microscope-slides, and lantern-slides were exhibited in illustration of the foregoing papers.

December 20th, 1922.

Prof. A. C. Seward, Sc.D., F.R.S., President,
in the Chair.

Robert Bleeck, A.R.S.M., 20 Liverpool Road, Kingston Hill (Surrey); Wilfred Norman Edwards, B.A., Assistant in the Geological Department of the British Museum (Natural History), Cromwell Road, S.W. 7; Charles Frederick Pilcher, 122 Windsor Road, Forest Gate, E. 7; and Ernest Bowes Tyrrell, B.A., 17 Camden Terrace, Clifton Vale, Bristol, were elected Fellows of the Society.

The List of Donations to the Library was read.

Prof. Owen Thomas Jones, M.A., D.Sc., F.G.S., gave a demonstration of the Crystallization of a Doubly-Refracting Liquid.

The following communications were read:—

1. 'A Micrometric Study of the St. Austell Granite (Cornwall).' By William Alfred Richardson, M.Sc., F.G.S.

2. 'The Petrography and Correlation of the Igneous Rocks of the Torquay Promontory.' By William George St. John Shannon, M.Sc., F.G.S.

Lantern-slides were exhibited in illustration of Mr. W. A. Richardson's paper, and rock-specimens and lantern-slides in illustration of Mr. W. G. Shannon's paper.

January 10th, 1923.

Prof. E. J. Garwood, Sc.D., F.R.S., Vice-President; and afterwards Prof. A. C. Seward, Sc.D., F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The following Fellows, nominated by the Council, were elected Auditors of the Society's Accounts for the preceding year:—Frederick Noel Ashcroft, M.A., and Richard Mountford Deeley, M.Inst.C.E.

Prof. William Johnson Sollas, Sc.D., F.R.S., F.G.S., then proceeded to deliver a lecture on Man and the Ice-Age.

He said that, thanks to the researches of General de Lamothe, Prof. Depéret, and Dr. Gignoux, the Quaternary System now takes its place as a marine formation in the stratified series.

Four ancient coast-lines, of remarkably constant height, have been traced around the Mediterranean Sea and along the western shores of the North Atlantic Ocean. These, with their associated sedimentary deposits, form the successive stages of the Quaternary System: namely, the Sicilian (coast-line about 100 metres); the Milazzian (coast-line about 60 m.); the Tyrrhenian (coast-line about 30 m.); and the Monastirian (coast-line about 20 m.).

The Sicilian deposits rest unconformably upon the Calabrian (Upper Pliocene), and in their lower layers contain a characteristic cold fauna. The fauna of the Milazzian is warm-temperate, of the Tyrrhenian and Monastirian still warmer, for they contain numerous species of mollusca which now live off the coast of Senegal and the Canary Islands.

The three lower coast-lines correspond with the three lower river-terraces of the Isser (Algeria), the Rhône, and the Somme. Hence it may be inferred that the position of the river-terraces has been determined by the height of the sea-level.

The lower gravels of the three lower terraces of the Somme all contain a warm fauna, *Elephas antiquus* and *Hippopotamus*, and thus (like the corresponding marine sediments) testify to a warm climate. The climate of the Quaternary age was, on the whole

warm-temperate or genial, but interrupted by comparatively short glacial intervals.

The outermost moraine (Mindel) of the Rhône Glacier is associated with the Milazzian terrace, the intermediate moraine with the Tyrrhenian, and the innermost moraine (Würm) with the Monastirian: except for their serial order, these associations are (in a sense) accidental.

It is now possible to assign the Palæolithic stages of human industry to their place in the Quaternary System: thus the 'Strepyan' or pre-Chellean is Milazzian in age; the typical Chellean—Tyrrhenian; the evolved Chellean, Acheulean, and Lower Mousterian—early Monastirian; and the Upper Mousterian, Aurignacian, Solutrian, and Magdalenian—later Monastirian.

The coast-lines of the Northern Hemisphere appear to have their counterparts in the Southern Hemisphere, and the researches of Dr. T. O. Bosworth in Peru and Prof. G. A. F. Molengraaff in the East Indies have revealed extensive marine Quaternary deposits and successive movements of the sea-level.

The Quaternary movements are probably due to a general deformation of the globe, involving eustatic changes in the level of the sea.

Discussion.

Mr. W. Whitaker noticed a matter as to which there seemed to be some doubt. While it was of great interest to hear of the agreement in levels of coastal beaches and of river-terraces, that agreement would seem to be limited to the estuarial part of the river-valleys. In the more inland parts the floor of the valleys rose, and the terraces might rise also: consequently, a terrace at, say, 100 feet in one place, would be at a higher level farther up the valley. In river-terraces inland one had to consider the height above the neighbouring river, rather than that above the sea.

Mr. Walter Johnson doubted whether eustatic movements of the sea could account for the facts as observed in the Lower Thames Basin. On that theory, we must suppose that the area maintained a fixed position with respect to the Earth's centre, and that each new base-level was provided by successive retreats of the sea, until, after the formation of the 'buried channel', the waters again advanced. It was just as reasonable to suppose that the movements of land and sea were mutual. The general parallelism of the Thames terraces far inland, with their almost uniform height above the river-bed, might perhaps accord with the marine theory. On the other hand, the depth and narrowness of the buried channel seem rather to indicate a late date for the climax of the Glacial Period, and to harmonize with G. K. Gilbert's observations on the pressure and erosive power of ice in Alaskan estuaries. The speaker asked whether the Lecturer considered that the third (40-metre) terrace of the Somme was cut in latest

Pliocene times, or not until Chellean times; and further in what manner it was suggested that Palæolithic implements were carried into the lœss of the Somme valley.

Mr. S. Hazzledine Warren was particularly pleased that the Lecturer did not follow the Penck theory of identification of the river-terraces with the glaciations: a theory which had always appeared untenable to the speaker. As the Lecturer had said, the river-terraces represented, not glaciations, but base-levels of erosion, and it must not be forgotten that the base-level of a river-valley was not a dead level with respect to the sea, but a curve which rose upwards inland.

The speaker wished to emphasize the importance of the cold marine fauna of the Sicilian stage, as that was the approximate time at which he believed the major glaciation of Europe to have occurred. Mr. M. A. C. Hinton and Mr. A. S. Kennard relied upon the poverty of palæontological evidence of cold in earlier Pleistocene times; but the Sicilian stage afforded another illustration of the proverbial danger of negative evidence.

Prof. J. E. Marr called attention to the difficulties which had attended attempts to draw up a classification of the deposits containing relics of Man in relationship to glacial accumulations. He felt that a study of the marine deposits would help greatly. As the features of terraces would be destroyed in areas which had undergone glaciation after their formation, he advocated a detailed study of the Pleistocene marine faunas of Britain, on the lines of the work of Prof. W. C. Brögger. There was much material, scattered through many museums in this country, which awaited the attention of an expert in Pleistocene conchology.

Prof. P. G. H. Boswell remarked that the work of Prof. Depéret on marine terraces in Western and Southern Europe had produced results so consistent as to be doubtful. In particular, being based on eustatic movements, it did not take into account the prevalent and important diastrophic movements that characterized late Pliocene and Pleistocene times. Other cogent arguments against Prof. Depéret's views had recently been published by F. Leverett,[1] E. de Martonne, and others.

As a result of his studies, Prof. Depéret had added yet another method to the already long list, by means of which the attempt at correlation of British and Continental Pleistocene deposits had been made. None of these methods had, up to the present, been entirely successful: local maximum glaciations were not necessarily synchronous; the range of the larger mammalian remains in British deposits was not established, and mixtures of faunas were detected; 'cultural drift' may have confused a possible correlation of deposits containing established types of implements, and so on. If, however, as a result of further work, it was found that several of these methods converged to give consistent results, a basis of correlation would be established. Before such could be

[1] Bull. Geol. Soc. Amer. vol. xxxiii (1922) p. 472.

effected, it was essential that we should be able to produce from this country evidence of a definite succession involving glacial deposits and evidences of Man for comparison with the foreign successions. The excavations necessary to establish this succession had recently been begun by Mr. J. Reid Moir in East Anglia, the geological evidence being collected by the speaker. Already excavations near Ipswich had indicated that brick-earths containing unabraded Acheulean implements overlay the Chalky-Kimmeridgian Boulder Clay, and were in turn overlain by disturbed gravels containing wisps of Boulder Clay and scratched and abraded Chellean and Mousterian implements. In view of the fact that Mr. Reid Moir claimed to have found pre-Chellean or early Chellean implements at the base of the Cromer Forest-Bed, and that remains of *Elephas antiquus* were most abundant in that deposit, a possible solution appeared to lie in the penecontemporaneity of the North-Sea Drift of Cromer ('Lower Glacial') and the Chalky-Kimmeridgian Boulder Clay ('Upper Glacial'). The latter did not mark the last glacial episode in the East of England. An intensely chalky Boulder Clay and deposits showing much (apparently glacial) disturbance occurred above it; these might, as Mr. Reid Moir contended, be correlated eventually with the Lower Mousterian deposits of the Continent.

Mr. H. Dewey called attention to the difficulty encountered in deciding to which terrace particular deposits belong. As implements of Chellean and Acheulean forms are, in many known instances, of the nature of derived fossils, they cannot be used to 'date' precisely the deposit in which they occur. The first working-sites are of Mousterian age, and this appears to be rather later than the 50-foot terrace. The raised beach at Brighton and Bembridge contains implements of Chellean and Acheulean forms; it appears to be contemporaneous with the 50-foot terrace, and possibly also with the raised beach of South Wales and the South of Ireland, which are covered with boulder-clays belonging to the period of maximum glaciation. But, according to the current view, the 50-foot terrace is later than the Chalky Boulder Clay, and hence arises a problem that remains to be solved.

Mr. K. S. Sandford remarked that the late Clement Reid[1] and Dr. A. E. Salter[2] had referred to the discovery of remains of *Elephas meridionalis* Nesti, and possibly of *E. antiquus*, in bedded Upper Pliocene deposits at Dewlish in Dorset. These beds rest, not in pipes as at Lenham, but upon the Chalk-surface at 350 feet above O.D.: they would seem to correspond to the deposits of the 100-metre Sicilian coast-line, and as such afford useful evidence in support of the faunal and stratigraphical sequence suggested by Prof. Depéret.

The Secretary read a letter from Mr. J. Reid Moir, expressing his regret that he was unable to be present at the lecture. The

[1] 'The Pliocene Deposits of Britain' Mem. Geol. Surv. 1890.
[2] Proc. Geol. Assoc. vol. xv (1897–98) p. 279.

belief that the English Palæolithic flint-implements of Chellean, Acheulean, and early Mousterian periods were of Interglacial age had been forced upon him by the results of his researches in East Anglia. That they had commonly been referred to post-Glacial times was, in his opinion, due to the fact that English geologists had confined their attention to gravel-deposits made up entirely of derived material, of which the implements formed a part. These, however, as in the similar case of Jurassic material found in post-Glacial gravels, must be referred to some pre-existing deposit or land-surface, and it was only the discovery of unabraded specimens resting upon or beneath undisturbed Glacial accumulations that was of any real value. He would like to call the attention of the Fellows present to his published views on the subject,[1] and to suggest that much important evidence might be forthcoming if detailed excavations were made in the Cromer Forest-Bed. He pointed out that there was no fixed agreement as to the exact type of implement indicated by the term Chellean, and urged the need of a satisfactory nomenclature for British Palæolithic deposits.

The Lecturer agreed with Mr. Whitaker in emphasizing the importance of measuring the height of river-terraces from the river and not from the sea-level. In reply to Mr. Johnson, he stated that he thought there was no difference of opinion as to the age of the Somme Valley: its excavation was completed down to the first terrace at the close of the Chellean; but he knew of no Chellean floors in that valley. Hunters often camped by the side of a river, and implements were frequently lost on its banks. In reply to Mr. Hazzledine Warren, he was inclined to think that the river-terrace was already in existence before it was covered by the moraine associated with it; but he had not seen sections that could dispose of this question one way or the other. Subsequent fan-deposits of outwashed gravel and other accidents would render investigation difficult, and might confuse the issue.

To other speakers he offered his apologies for his imperfect hearing, which had prevented him from following closely their remarks.

January 24th, 1923.

Prof. A. C. Seward, Sc.D., F.R.S., President, in the Chair.

Donald Ferbys Wilson Baden-Powell, B.A., Oriel College, Oxford; Ernest Charles Clutterbuck, Manland Beacon, Harpenden (Hertfordshire); and Edgar Morton, B.Sc., 9 Ashfield Grove, Rusholme, Manchester, were elected Fellows of the Society.

[1] Geol. Mag. 1920, p. 221.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On Reptilian Remains from the Karroo Beds of East Africa.' By Sidney Henry Haughton, B.A., D.Sc., F.G.S. (Read by Dr. A. Smith-Woodward, F.R.S., Pres.L.S., F.G.S.)

2. 'Glacial Succession in the Thames Catchment-Basin.' By the Rev. Charles Overy, M.A., F.G.S.

Lantern-slides were exhibited in illustration of Dr. S. H. Haughton's paper, and lantern-slides and Palæolithic implements in illustration of the Rev. Charles Overy's paper.

February 7th, 1923.

Prof. A. C. Seward, Sc.D., F.R.S., President,
in the Chair.

John Edward Alfred Whealler, B.A., 34 The Waldrons, Croydon (Surrey); and Eric Stewart Willbourn, B.A., Assistant Geologist to the Federated Malay States, Batu Gajah (F.M.S.), were elected Fellows of the Society.

The List of Donations to the Library was read.

Mr. G. Vibert Douglas then proceeded to deliver a lecture on the Geological Results of the Shackleton-Rowett (*Quest*) Expedition. The Lecturer said that St. Vincent and St. Paul's Rocks were examined on the way out, but the more detailed work commenced in South Georgia. This island lies 900 miles east of Cape Horn, and is 100 miles long by 20 miles in width. Its topographical features are those of an upland dissected by glacial action. The glaciers in general show signs of withdrawal. Geologically, the island is composed of sedimentary rocks and, at the south-eastern end, igneous rocks. These have been classified by Mr. G. W. Tyrrell as follows:

Sedimentary Rocks...	(1) Mudstones, shale, slate, phyllite.
	(2) Quartzite, greywacké.
	(3) Calcareous rocks.
	(4) Tufaceous rocks.
Igneous Rocks	(1) Gabbros and peridotite.
	(2) Dioritic and granitic rocks.
	(3) Dolerites and basalts.
	(4) Spilitic lavas and epidosites.

The question as to whether the sediments represent one continuous period of deposition is open to dispute. The Lecturer thought that there were two distinct periods, divided by an

unconformity. Definite fossil evidence is difficult to obtain, but *Araucarioxylon* has been identified by Prof. W. T. Gordon, which would point to an age not older than Lower Carboniferous. This fossil came from the Bay of Isles, and was found in what the Lecturer believes to be the younger series. The rocks all show signs of metamorphism, and the strike of the folds and lamellæ of the phyllites would point to the fact that the pressure came either from the south-south-west or from the north-north-east. Considerable faulting was observed, both normal and reversed.

The igneous complex east of Cooper Bay can be differentiated into two separate areas: (1) north of Drygalski Fjord, and (2) at Larsen Harbour. In the former area quartz-diorite, peridotite, aplite, and syenitic lamprophyre with basement gabbro occur; in the latter area were found spilitic lavas (containing much epidote) and basement gabbro. The general types are not Andean.

Elephant Island is situated in the Powell Group of the South Shetlands. Topographically, it is an ice-covered plateau rising to about 1200 or 1500 feet above sea-level. The rocks on the northern shore have been described by Mr. Wordie as contorted phyllites. The Lecturer's observations at Minstrel Bay on the western coast showed that the rocks there were similar. At Cape Lookout, on the south side of the island, a metamorphic series was encountered: this, according to Dr. C. E. Tilley, consists of amphibolite, garnet-albite-schist, quartz-hornblende-epidote-schist, and banded sandy limestone.

Observations from the ship were made of the volcanic island of Zavodovski, in the South Sandwich Group. The Tristan da Cunha Group in the Southern Atlantic, 1500 miles west of the Cape of Good Hope, was also visited. The islands are of volcanic origin. Particular attention was paid to the existence of Middle Island.

Gough Island lies more than 200 miles south of the Tristan da Cunha Group, and is 8 miles long by 3 miles in width. It is a monoclinal block, with dip-slopes to the west and escarpments to the east. The lavas forming these features are basaltic, and intrusive into these lavas is a trachytic stock. Following this intrusion, the basalts were cut by a series of doleritic dykes. In general, it may be said that Gough Island presents many features similar to those that characterize the islands of Ascension and St. Helena.

Discussion.

Mr. J. Quiller Rowett laid stress on the fact that Shackleton's great ideal was to promote the progress of science and to facilitate scientific research. The Expedition had added to our history a page worthy of the highest traditions of British exploration and British endeavour.

Mr. W. Campbell Smith said that the rocks collected by the Lecturer on Gough I. and in the Tristan da Cunha Group would prove of great value. Despite the fact that the Lecturer had

collected his specimens under difficulties and on very rapid traverses, they were all accurately localized. With the exception of some of the specimens collected on Gough I. by the *Scotia* Expedition, earlier descriptions of rocks from these islands were based on pebbles or poorly-localized specimens. As a result of the *Quest* Expedition nearly all the types recorded had now been found in place, and there would be sufficient material available for analysis. The rock collected on Rowett's Peak (on Gough I.) proved to be an essexite. 'The Apostle' was formed of ægirine-trachyte containing a problematical mineral (described by Dr. Campbell), believed by the speaker to be an iron-rich member of the olivine group. The rocks of the Tristan da Cunha Group included basalts and hornblende-bearing trachy-basalts, with trachytic lavas on Nightingale and Middle Islands. The rock described by A. Renard as 'bronzite-andesite' had been found *in situ*, and the 'bronzite' appeared to be an olivine similar to that found in the trachyte of 'The Apostle' on Gough Island.

Mr. J. M. Wordie remarked that the rocks from Elephant I. were of the same nature as the few specimens collected by the shipwrecked *Endurance* party in 1916, and the island may, therefore, be regarded as composed throughout of crystalline schists in different degrees of metamorphism. The Lecturer's work on South Georgia would undoubtedly help to elucidate some of the numerous problems presented by that island. Although only one fossil was unearthed, its importance was considerable, for it increased the probability that the Cumberland Bay Series is of Mesozoic, rather than of Palæozoic, age. The Lecturer appeared to have had the same difficulty in accepting Mr. Ferguson's interpretation of the tectonics and stratigraphy as the speaker himself felt in 1914. It is very doubtful whether there are any unconformities in South Georgia. The Lecturer had cited a case with some evidence of one; but, in view of the identity of strikes and of rock-types, would not reversed faults and very sharp folds explain the conditions more easily? Folds of this nature were very obvious in some of the excellent photographs which the Lecturer had shown on the screen.

Prof. W. T. Gordon said that the Lecturer had referred to a plant petrifaction from South Georgia which the speaker was permitted to examine. The specimen was very imperfectly preserved, for each cell had been disintegrated to such an extent that only the outline remained. Yet, small as were the fragments, they were sufficiently large to allow of differentiation into pith and secondary wood. The wood could be proved to belong to the type *Araucarioxylon*, and the minute structure of the pits on the cell-walls of the wood favoured a Mesozoic, rather than a Palæozoic, age for the specimen. It was impossible, on account of the poor preservation of the plant, to say whether it could be correlated with *Antarcticoxylon*, and therefore with the Triassic genus *Rhexoxylon* from South Africa. The balance of the characters seemed to incline towards a Mesozoic age for the beds.

The ash in which the specimen was found had suffered decomposition, and this suggested some confirmation of the theory which the speaker had advanced, that petrification was effected by colloidal solutions. The colloid would be absorbed by the plant-fragments, and the slightest decay of these would cause the colloid to 'gelate.' The gel would no longer be able to escape through the cell-membranes, and would ultimately be deposited on the cell-walls. In this way petrification would be initiated, and the agate-structure so frequently observed in each cell of a petrified plant could be easily and adequately explained. In well-known localities for petrified plants, both in this country and abroad, decomposed volcanic ashes were associated with the fossils, the latter occurring in the ash itself or in ashy sandstones. As localities for examples in this country, Rhynie, Pettycur, Gullane, Lennel Braes, Duns, etc. might be cited.

The structure of the coal-balls of Lancashire seems to be inconsistent with this theory; but there were probably other methods of producing colloidal solutions, and there are some signs in the coal-balls that such solutions were present, such as the fibrous radiate structure of the matrix. In any case, the specimen from South Georgia occurred in a decomposed ash, and gave some confirmation of the general theory that, in volcanic ashes which are in process of decomposition, the conditions are suitable for the petrification of vegetable fragments, because they favour the production of colloidal solutions.

Dr. J. W. Evans agreed that the rocks of South Georgia and Elephant I. showed no affinities with the Andes, but neither did the rocks of the centre and east of South America, and so it was still possible that they might represent part of that continent which had been left behind in a westward movement. The facts disclosed by the Lecturer were consistent with either theory of the origin of the Atlantic (that which attributed it to the foundering of former land, and that which supposed that the adjoining continents had drifted apart) or with a combination of both hypotheses, which the speaker favoured. He asked whether any of the islands contained erratics that might be attributed to ice-transport, when the climate was more severe and the sea stood at a higher level.

Mr. G. M. Part referred to the very welcome addition which the Expedition had made to our knowledge of the Cape Verde Islands. Apart from Dr. A. Harker's description of the *Beagle* Collection, and certain work which was supposedly proceeding in Germany (but of which there were no results published as yet), there had been no very recent descriptions of these rocks. The island of St. Vincent consisted of the broken-down remains of a strato-volcano with a central core of plutonic types. The *Quest* Expedition had not collected any of these latter, owing to the shortness of the time available, but had brought back a number of interesting nepheline-bearing lavas (nepheline-basalts, basanites, and analcite-basalts) as well as limestones associated with them, and specimens of dykes similar petrographically to the lavas.

ANNUAL GENERAL MEETING.

February 16th, 1923.

Prof. Albert Charles Seward, Sc.D., F.R.S.,
President, in the Chair.

Report of the Council for 1922.

During the year 84 new Fellows were elected into the Society (28 more than in 1921). Of the Fellows elected in 1922, 67 paid their Admission Fees before the end of that year, and, of the Fellows who had been elected in the previous year, 10 paid their Admission Fees in 1922, making the total accession of new Fellows during the past year amount to 77 (6 more than in 1921).

Allowing for the loss of 41 Fellows (14 resigned, 24 deceased, and 3 removed), it will be seen that there is an increase of 36 in the number of Fellows (as compared with an increase of 14 in 1921).

The total number of Fellows is, therefore, at present 1279, made up as follows: Compounders 195 (3 less than in 1921); Contributing Fellows 1075 (39 more than in 1921); and Non-Contributing Fellows 9 (the same as in 1921).

Turning to the Lists of Foreign Members and Foreign Correspondents, the Council announces with regret the decease during the past year of Senator Giovanni Capellini, Commendatore Arturo Issel, and Dr. Hans Reusch, Foreign Members, and of Prof. Theodor Liebisch and Prof. Ernst Weinschenk, Foreign Correspondents. There are now six vacancies in the list of Foreign Members, and fourteen vacancies in the list of Foreign Correspondents.

The total Receipts from all ordinary sources of income amounted to £4110 7*s.* 8*d.*, and the ordinary Expenditure of the year to £3806 16*s.* 10*d.* In addition, there was Special Expenditure on arrears of publication amounting to £385 10*s.* 0*d.*, and there were Special Receipts amounting to £175 6*s.* 2*d.*, including a grant of £100 from the Royal Society (in respect of the List of Geological Literature for 1914) and transfers from the Sorby and Hudleston Bequests.

Vol. LXXVIII of the Quarterly Journal for 1922 was completed by the publication of the fourth part on December 30th of that year. It contained thirteen papers, published at a cost of £1082 5*s.* 3*d.* These papers include all but three of those read before the Society up to the end of December 1921. There now remain outstanding about twenty papers which have been read during the present Session and in 1921. The Council, recognizing

the seriousness of this situation, contemplates the raising of a voluntary fund among the Fellows in order to clear off these arrears.

The facts regarding the publication of the Lists of Geological Literature are set forth in the Report of the Library Committee.

The Apartments of this Society have been used for General Meetings and for Council or Committee Meetings during the past year by the Institution of Mining Engineers, the Institution of Mining & Metallurgy, the Institution of Water Engineers, the Society of Engineers, the Mineralogical Society, the Palæontographical Society, the Ray Society, the Persia Society, the Geologists' Association, and the South-Eastern Union of Scientific Societies.

Under the will of the late Charles Papps Gloyne, the Society received during the year a sum which has been invested in £1676 17*s*. 6*d*. 3½ per cent. Conversion Loan (1961), for the purpose of establishing a Trust Fund, to be known as the Gloyne Outdoor Geological Research Fund. The regulations determining the appropriation of the income of this Fund have been drawn up in conformity with counsel's opinion, and an announcement will be issued in due course, inviting suggestions for the use of the fund.

Sir Aubrey Strahan and Mr. R. D. Oldham (afterwards replaced by Prof. A. C. Seward) acted as the Society's representatives on the Conjoint Board of Scientific Societies.

The Society was represented at the Brussels International Geological Congress by Dr. J. W. Evans and Dr. J. S. Flett; at the Centenary Celebration of the Yorkshire Philosophical Society by Prof. A. C. Seward; at the 700th Anniversary of the University of Padua by Mr. G. M. Trevelyan; and at the 150th Anniversary of the Royal Academy of Belgium by Prof. Louis Dollo.

Mr. W. Whitaker was nominated as Delegate to the Bournemouth Congress of the Royal Sanitary Institute, and Mr. G. W. Lamplugh as Delegate to the Conference of Corresponding Societies at the British Association Meeting in Hull.

The Proceeds of the Daniel-Pidgeon Fund for 1922 were awarded to Mr. Herbert Price Lewis, of Sheffield University, who originally proposed to carry out researches on the Structure of certain Caninoid Corals occurring in the Carboniferous Limestone of North Wales at horizons higher than their reputed range; but he has since asked to be allowed to change the object of his research to the investigation of the distinction between the genera *Caninia* and *Campophyllum*.

Further, the following Awards of Medals and Funds have been made:—

The Wollaston Medal to Mr. William Whitaker, in recognition of his long-continued researches concerning the mineral structure of the Earth, especially in connexion with the water-supply and underground geology of Surrey, Norfolk, and other parts of England, and of his earlier work on the Tertiary strata of the London and Hampshire Basins.

The Murchison Medal, together with a sum of Ten Guineas from the Murchison Geological Fund, to Prof. John Joly, as an acknowledgment of the value of his researches on the thermal properties of minerals, on the relations of radioactivity to geology, and of his estimations of the age of the Earth arising therefrom.

The Lyell Medal, together with a sum of Twenty-five Pounds from the Lyell Geological Fund, to M. Gustave F. Dollfus, as a mark of honorary distinction, and in recognition of the value of his researches on the Tertiary strata of the Paris Basin and other parts of Europe.

The Bigsby Medal to Mr. Edward Battersby Bailey, M.C., as an acknowledgment of eminent services rendered by his researches on the tectonics of the South-West Highlands of Scotland.

The Balance of the Proceeds of the Wollaston Donation Fund to Mr. Harold Herbert Read, in recognition of the value of his work on the rocks of Aberdeenshire and Banffshire.

The Balance of the Proceeds of the Murchison Geological Fund to Mr. Thomas Henry Withers, as a mark of appreciation of his contributions to our knowledge of the Cirripedes.

A Moiety of the Balance of the Lyell Geological Fund to Prof. William Noel Benson, in recognition of the value of his researches in petrology, especially in connexion with the igneous rocks of New South Wales and of other parts of Australia and of Antarctica.

A Moiety of the Balance of the Lyell Geological Fund to Prof. William Thomas Gordon, in recognition of the value of his researches on the Fossil Plants of Pettycur (Fife), and of his more recent work on *Archæocyathus* from Antarctica.

Report of the Library Committee for 1922.

The Accessions to the Library during the year have not differed greatly in amount from those in previous years. The number of complete volumes received is larger than in the two preceding years, while that of detached parts and pamphlets shows a slight decrease. Mention may be made of seventeen volumes (consisting chiefly of text-books and standard works on ore-deposits) presented by Mrs. Zabel from the library of the late Mr. C. F. Zabel, F.G.S.

The Donations received during the year number 72 volumes of separately-published works, 410 pamphlets, and 3 detached parts of works; also 179 volumes and 341 detached parts of serial publications, 182 volumes and 328 parts of the publications

of Geological Surveys and other public bodies, and 9 volumes of weekly periodicals.

Further, 95 sheets of geological maps were received during the year.

The number of accessions by donation amounts, therefore, to 442 volumes, 410 pamphlets, and 672 detached parts. The Donors during 1922 included 131 Government Departments and other public bodies, 134 Societies and Editors of periodicals, and 102 individuals.

Further progress has been made in the resumption of exchanges with Societies, Government Departments, and other Institutions on the Continent, with which relations had been suspended during the war. The Library now receives the publications of nearly all such Institutions, although in some cases it has been found impossible to obtain complete sets for the interrupted period.

During the year 137 volumes have been bound. Owing to the high cost of binding, only the most necessary work of this description has been undertaken, and a great many books are at present unbound or awaiting repair, representing the accumulation of several years during which expenses under this heading have been reduced to the minimum.

The purchases during the year included 11 volumes and 28 detached parts of works, and 41 volumes and 48 detached parts of works published serially, and 2 sheets of geological maps. Among these works were the following :—

C. K. Leith, 'Economic Aspects of Geology' 1922 ; J. W. Gregory, 'Rift-Valleys & Geology of East Africa' 1921 ; W. E. Ford, 'Dana's Text-book of Mineralogy' 3rd ed. 1922 ; R. A. S. MacAlister, 'A Text-book of European Archæology, i—Palæolithic Period' 1921 ; A. Wegener, 'Die Entstehung der Kontinente & Ozeane' 3rd ed. 1922 ; R. L. Sherlock, 'Man as a Geological Agent' 1922 ; Travaux du Laboratoire de Géologie de la Faculté des Sciences de Lyon, Fasc. 1—A. Riche & F. Roman, 'La Montagne de Crussol, Étude Stratigraphique & Paléontologique' 1921 ; Fasc. 2—'Monographie Paléontologique de la Faune de Vertébrés des Sables de Montpellier, I—Les Baleinoptères (Mémoire posthume de Maurice Gennevaux, rédigé & complété par F. Roman)' 1922 ; The Johns Hopkins University Studies in Geology : No. 1—J. T. Singewald, Jr., & E. W. Berry, 'The Geology of the Corocoro Copper-District of Bolivia' 1922 ; No. 2—J. T. Singewald Jr., & E. W. Berry, 'Geology & Palæontology of the Huancavelica Mercury-District' 1922 ; No. 3—E. M. Spicker, 'The Palæontology of the Zorritos Formation of the North Peruvian Oilfields' 1922 ; and No. 4—E. W. Berry, 'Contributions to the Palæobotany of Peru, Bolivia, & Chile' 1922.

Also a geological map of Morocco, by L. Gentil, 1 : 1,500,000, 1920 ; and a geological map of French Equatorial Africa, by E. Loir, 1 : 5,000,000, 1913.

The number of volumes borrowed from the Library during 1922 was 1135. Of this total 663 were taken personally by Fellows, and 472 were sent through the post. In addition, it is estimated that the Library was used for purposes of reference and study on nearly 1500 occasions.

The List of Geological Literature for 1914 (No. 21) was completed and published during the year under review. The List for the years 1915–19 is at present in the press. These two volumes

cover the whole period during which no List could be published, and they are each provided with a subject-index. It has not been found possible to resume the preparation of a subject-index to the Lists for current years, and the volume for 1921 was, therefore, published in April 1922 as an Author-Index only. The List of Geological Literature for last year, compiled on the same plan, is now in the press. The incorporation in the Card Catalogue of the List for 1921 has been completed.

The ordinary Expenditure incurred in connexion with the Library during the year 1922 was as follows :—

	£	s.	d.
For Books and Periodicals	77	6	6
For Binding	46	10	6
For Catalogue Cards	6	0	0
For Sundries		18	0
Total	£130	15	0

The appended Lists contain the Names of Government Departments and other Public Bodies, Societies, Editors, and Personal Donors, from whom Donations to the Library have been received during the year under review :—

I. Government Departments and other Public Bodies.

Alabama.—Geological Survey. Montgomery (Ala.).
American Museum of Natural History. New York.
Australia, Government of the Commonwealth of.
Australia (South), etc. *See* South Australia, *etc.*
Austria.—Geologische Staatsanstalt. Vienna.
Baden.—Geologische Landesanstalt. Heidelberg.
Belgium.—Académie Royale des Sciences, des Lettres & Beaux-Arts de Belgique. Brussels.
Bergens Museum. Bergen.
Berlin.—Preussische Akademie der Wissenschaften.
Bristol Museum & Art Gallery.
British Columbia.—Ministry of Mines. Victoria (B.C.).
Brussels.—Musée Royale d'Histoire Naturelle de Belgique.
Buenos Aires.—Museo Nacional.
California.—Academy of Sciences. San Francisco.
——, University of. Berkeley (Cal.).
Cambridge (Mass.).—American Academy of Arts & Sciences.
——. Museum of Comparative Zoology in Harvard College.
Canada.—Geological & Natural History Survey. Ottawa.
——. Department of Mines.
Cape Town.—South African Museum.
Colorado Springs.—Colorado College.
Connecticut.—State Geological & Natural History Survey. Hartford (Conn.).
Copenhagen.—Komitteen for Kap York Stationen, Thule.
Córdoba (Argentine Republic).—Academía Nacional de Ciencias.
Czecho-Slovakia.—Státního Geologického Ústavu. Prague.

Denmark.—Geologiske Undersögelse. Copenhagen.
——. Kommission for Ledelsen af de Geologiske & Geografiske Undersögelser i Grönland. Copenhagen.
Dublin.—Royal Irish Academy.
Egypt.—Ministry of Finance (Survey Department). Cairo.
——. ——. Mines & Quarries Department. Cairo.
Federated Malay States.—Government Geologist. Kuala Lumpur.
Finland.—Finlands Geologiska Undersökning. Helsingfors.
France.—Ministère de l'Instruction Publique. Paris.
——. Muséum d'Histoire Naturelle. Paris.
——. Service Hydrographique de la Marine. Paris.
Gold Coast.—Geological Survey. Accra.
——. Mines Department. Accra.
Great Britain.—Colonial Office. London.
——. Geological Survey. London.
——. Imperial Institute. London.
——. Imperial Mineral Resources Bureau. London.
——. Mines Department. London.
——. Ordnance Survey. Southampton.
Hesse.—Geologische Landesanstalt. Darmstadt.
Holland.—Departement van Kolonien. The Hague.
Honolulu.—Bernice P. Bishop Museum.
——. Hawaiian Volcano Observatory.
Hungary.—Ungarische Geologische Anstalt (Magyar Földtani Tarsulat). Budapest.
Illinois.—Geological Survey. Urbana (Ill.).
——. State Museum. Springfield (Ill.).
India.—Geological Survey. Calcutta.
——. Mines Department. Calcutta.
——. Trigonometrical Survey. Dehra Dun.
Indo-China.—Service Géologique. Hanoi-Haiphong.
Iowa.—Geological Survey. Des Moines.
Ireland.—Geological Survey. Dublin.
Japan.—Earthquake-Investigation Committee. Tokio.
——. Geological Survey. Tokio.
——. National Research Council. Tokio.
Kansas University. Lawrence (Kan.).
Kentucky.—Geological Survey. Frankfort (Ky.).
Lausanne.—University of.
London.—British Museum (Natural History).
——. Museum of Practical Geology.
Madrid.—Museo de Ciencias Naturales.
——. Real Academía de Ciencias Exactas, Físicas & Naturales.
Mexico.—Instituto Geológico. Mexico City.
——. Secretaria de Industria, Comercio & Trabajo. Mexico City.
Milan.—Reale Istituto Lombardo di Scienze & Lettere.
Minnesota.—School of Mines. Minneapolis.
Missouri University: School of Mines & Metallurgy. Rolla (Mo.).
Munich.—Bayerische Akademie der Wissenschaften.
Mysore.—Geological Department. Bangalore.
Nancy.—Académie de Stanislas.
New Jersey.—Department of Conservation. Trentham (N.J.).
New South Wales.—Department of Mines. Sydney.
——. Geological Survey. Sydney.
New York State Museum. Albany (N.Y.).
New Zealand.—Board of Science & Art. Wellington.
——. Department of Mines. Wellington.
——. Dominion Museum. Wellington.
——. Geological Survey. Wellington.
Nigeria.—Geological Survey.
Norway.—Geologiske Undersökelse. Christiania.
Norwich Castle Museum Committee.
Ohio.—Geological Survey. Columbus.
Ontario.—Department of Mines. Toronto.
Padua.—Istituto Geologico della R. Università.
——. Reale Accademia delle Scienze.
Paris.—Académie des Sciences.

Peru.—Ministerio de Fomento. Lima.
Philippine Is.—Department of the Interior: Bureau of Science. Manila.
Poland.—Service Géologique. Warsaw.
Quebec.—Department of Colonization, Mines, & Fisheries.
Queensland.—Department of Mines. Brisbane.
——. Geological Survey. Brisbane.
Rhodesian Museum. Bulawayo.
Rome.—Reale Accademia dei Lincei.
Rumania.—Academia Română. Bucarest.
——. Institutului Geologic. Bucarest.
Russian Far East.—Geological Committee. Vladivostok.
Scotland.—Geological Survey. Edinburgh.
Sierra Leone.—Geological Survey. Freetown.
South Africa.—Department of Mines. Pretoria.
——. Geological Survey. Pretoria.
South Australia. Department of Mines. Adelaide.
——. Geological Survey. Adelaide.
South Dakota School of Mines. Rapid City.
Southern Rhodesia.—Geological Survey. Salisbury.
Spain.—Instituto Geologico. Madrid.
——. Spanish Embassy in London.
Stockholm.—Kongliga Svenska Vetenskaps Akademi.
Sweden.—Statens Järnvägars Geotekniska Kommission. Stockholm.
——. Sveriges Geologiska Undersökning. Stockholm.
Switzerland.—Geologische Kommission der Schweiz. Berne.
Tasmania.—Secretary for Mines. Hobart.
Tôhoku.—Imperial University of Sendai.
Tokio.—College of Science.
United States.—Department of Commerce: Coast & Geodetic Survey. Washington (D.C.).
——. Geological Survey. Washington (D.C.).
——. National Academy of Sciences & National Research Council. Washington (D.C.).
——. National Museum. Washington (D.C.).
Victoria (Australia). Geological Survey. Melbourne.
Vienna.—Akademie der Wissenschaften.
——. Naturhistorisches Hofmuseum.
Washington University. St. Louis (Mo.).
Washington (D.C.).—Carnegie Institution.
——. Geophysical Laboratory.
——. Smithsonian Institution.
West Indies.—Imperial Agricultural Department. Bridgetown (Barbados).
Western Australia.—Department of Mines. Perth.
——. Geological Survey. Perth.

II. Societies and Editors.

Adelaide.—Royal Society of South Australia.
Agram.—Societas Historico-Naturalis Croatica.
Basel.—Naturforschende Gesellschaft.
Belfast.—Natural History Society.
Bergen.—'Naturen.'
Berlin.—Deutsche Geologische Gesellschaft.
——. Gesellschaft Naturforschender Freunde.
——. Zeitschrift für Berg-, Hütten-, und Salinenwesen.
Berne.—Naturforschende Gesellschaft.
Bombay Branch of the Royal Asiatic Society.
Bonn.—Naturhistorischer Verein der Preussischen Rheinlande.
Bordeaux.—Société Linnéenne.
Boston (Mass.).—American Academy of Arts & Sciences.
Bristol Naturalists' Society.
Brussels.—Société Belge de Géologie.
——. Société Royale Zoologique & Malacologique de Belgique.

Buenos Aires.—Sociedad Cientifica Argentina.
Caen.—Société Linnéenne de Normandie.
Calcutta.—Asiatic Society of Bengal.
——. Institute of Engineers (India).
Cambridge Philosophical Society.
Cape Town.—Royal Society of South Africa.
——. South African Association for the Advancement of Science.
Cardiff.—South Wales Institute of Engineers.
Chicago.—'Journal of Geology.'
Christiania.—Nyt Magazin for Naturvidenskaberne.
Copenhagen.—Dansk Geologisk Forening.
Denver.—Colorado Scientific Society.
Dijon.—Académie des Sciences.
Dorchester.—Dorset Natural History & Antiquarian Field-Club.
Dorpat.—Naturforschende Gesellschaft.
Dresden.—Naturwissenschaftliche Gesellschaft 'Isis.'
Dublin.—Royal Dublin Society.
Edinburgh.—Royal Scottish Geographical Society.
——. Royal Society.
Frankfurt am Main.—Senckenbergische Naturforschende Gesellschaft.
Geneva.—Société de Physique & d'Histoire Naturelle.
Giessen.—Oberhessische Gesellschaft für Natur- und Heilkunde.
Gloucester.—Cotteswold Naturalists' Field-Club.
Hague.—Société Hollandaise des Sciences.
Halifax (Nova Scotia).—Nova Scotian Institute of Science.
Halle a. d. Saale.—Zeitschrift für Praktische Geologie.
Hanau.—Wetterauische Gesellschaft für Naturkunde.
Hermannstadt.—Siebenbürgischer Verein für Naturwissenschaften.
Hobart.—Royal Society of Tasmania.
Hull Geological Society.
Jena.—Geologische & Paläontologische Abhandlungen.
Johannesburg.—Geological Society of South Africa.
Lancaster (Pa.).—'Economic Geology.'
Lausanne.—Société Vaudoise des Sciences Naturelles.
Leeds Geological Association.
Leicester Literary & Philosophical Society.
Leipzig.—Zeitschrift für Krystallographie.
Liége.—Société Géologique de Belgique.
——. Société Royale des Sciences de Liége.
Lima.—Asociación Peruana para el Progreso de la Ciencia.
Liverpool Geological Society.
—— Literary & Philosophical Society.
London.—British Association for the Advancement of Science.
——. Chemical Society.
——. 'The Chemical News.'
——. 'The Colliery Guardian.'
——. 'The Geological Magazine.'
——. Geologists' Association.
——. Institution of Civil Engineers.
——. Institution of Mining Engineers.
——. Institution of Mining & Metallurgy.
——. Institution of Water Engineers.
——. Iron & Steel Institute.
——. Linnean Society.
——. 'The London, Edinburgh, & Dublin Philosophical Magazine.
——. Mineralogical Society.
——. Mining Journal.
——. 'The Mining Magazine.'
——. 'The Nation & the Athenæum.'
——. 'Nature.'
——. 'The Naturalist.'
——. 'Oil-Engineering & Finance.'
——. Palæontographical Society.
——. 'The Quarry.'
——. Royal Agricultural Society.
——. Royal Geographical Society.
——. Royal Institution.

London.—Royal Meteorological Society.]
——. Royal Microscopical Society.
——. Royal Photographic Society.
——. Royal Society.
——. Royal Society of Arts.
——. Society of Engineers.
——. Victoria Institute.
——. 'Water.'
——. Zoological Society.
Manchester.—Literary & Philosophical Society.
Melbourne (Victoria).—Australasian Institute of Mining & Metallurgy.
——. Royal Society of Victoria.
——. 'The Victorian Naturalist.'
Mexico.—Sociedad Científica 'Antonio Alzate.'
Milan.—Società Italiana di Scienze Naturali.
Naples.—Accademia delle Scienze Fisiche e Matematiche.
Newcastle-upon-Tyne.—University of Durham Philosophical Society.
New Haven (Conn.).—Academy of Arts & Sciences.
——. 'The American Journal of Science.'
New York.—American Institute of Mining & Metallurgical Engineers.
Northampton.—Northamptonshire Natural History Society.
Ottawa.—Royal Society of Canada.
Paris.—Annales des Mines.
——. Société Géologique de France.
Perth.—Perthshire Society of Natural Sciences.
Philadelphia.—Academy of Natural Sciences.
——. American Philosophical Society.
Pisa.—Società Toscana di Scienze Naturali.
Plymouth.—Devonshire Association for the Advancement of Science.
Rennes.—Société Géologique & Minéralogique de Bretagne.
Rochester Academy of Sciences.
Rome.—Società Geologica Italiana.
Rugby School Natural History Society.
Santiago de Chile.—Sociedad Nacional de Minería.
Stockholm.—Geologiska Förening.
Stratford.—Essex Field-Club.
Stuttgart.—Centralblatt für Mineralogie, &c.
——. Verein für Naturkunde Württembergs.
Sydney (N.S.W.).—Linnean Society of New South Wales.
Toronto.—Royal Canadian Institute.
Toulouse.—Société d'Histoire Naturelle.
Upsala.—Geological Institution of the University.
Vienna.—Geologische Gesellschaft.
——. Berg- und Hüttenmännisches Jahrbuch.
——. Zoologisch-Botanische Gesellschaft.
Washington (D.C.).—Geological Society of America.
Wellington.—New Zealand Institute.
Whitby Literary and Philosophical Society.
Wiesbaden.—Nassauischer Verein für Naturkunde.
Worcester.—Naturalists' Club.
York.—Yorkshire Philosophical Society.

III. Personal Donors.

Abbott, W. J. L.
Adams, H.
Assmann, P.

Baschin, O.
Bonney, T. G.
Boswell, P. G. H.
Bosworth, T. O.
Boule, M.
Buckman, S. S.
Burkitt, M. C.
Burling, L. D.

Calman, W. T.
Chandler, Miss M. E. J.
Chapman, F.
Chatley, H.
Cole, G. A. J.
Cortázar, D. de.
Créqui-Montfort, G. de.
Crompton, H.

Dalloni, M.
Dal Piaz, G.
Davis, W. M.
Davison, C.
Davisor, E. H.
Depape, G.
Dixey, F.
Douvillé, H.
Du Toit, A. L.

Elles, Miss G. L.

Fox, C. S.

Galloway, W.
Goldman, M. I.
Goldschmidt, V. M.
Gomez, J. R.
Grabham, G. W.
Gregory, J. W.

Harger, H. S.
Hatch, F. H.
Haughton, S. H.
Heim, Albert.
Hooley, R. W.
Howchin, W.

Jillson, W. R.

Kay, H.
Kayser, E.
Kendall, P. F.
Kiær, J.

Lacroix, A.
Lamplugh, G. W.
Lencewicz, S.
Linstow, O. V.
Liversidge, A.

Manson, M.
Margerie, E. de.
Marsters, E. V.
Matley, C. A.
Matousek, O.
Maufe, H. B.
Milner, H. B.
Moir, J. R.
Murakami, H.

Nopcsa, Baron F.

Oldham, R. D.
Osborn, H. F.

Parker, W. R.
Parkinson, J.
Penck, A.
Penzer, N. M.
Plymen, G. H.

Richardson, W. A.
Roccati, A.
Rogers, I.
Rotman, D.

Seidlitz, W. von.
Seward, A. C.
Sheppard, T.
Smith, W. Campbell.
Spath, L. F.
Speight, R.
Stanley, E. R.
Stansfield, J.
Süssmilch, C. A.

Taber, S.
Teilhard de Chardin, P.
Termier, P.
Thomas, Herbert H.
Thompson, B.
Torcelli, A. J.

Van Baren, J.
Vaughan, T. W.

Wallis, F. S.
Walther, J.
Washington, H. S.
Weber, M.
Wentworth, C. K.
Werth, E.
Whitaker, W.
Withers, T. H.
Woods, H.
Woolacott, D.

Yakovlev, N.

Zabel, Mrs.

Comparative Statement of the Number of the Society at the Close of the Years 1921 and 1922.

	Dec. 31st, 1921.		Dec. 31st, 1922.
Compounders	198	....	195
Contributing Fellows	1036	....	1075
Non-Contributing Fellows	9	....	9
	1243		1279
Foreign Members	37	....	34
Foreign Correspondents	28	....	26
	1308		1339

Comparative Statement, explanatory of the Alterations in the Number of Fellows, Foreign Members, and Foreign Correspondents at the close of the Years 1921 and 1922.

Number of Compounders, Contributing, and Non-Contributing Fellows, December 31st, 1921 ...		1243
Add Fellows elected during the former year and paid in 1922		10
Add Fellows elected and paid in 1922		67
		1320
Deduct Compounders deceased	9	
Contributing Fellows deceased	15	
Contributing Fellows resigned	14	
Fellows removed in accordance with Sect. VI, Art. 5, of the Bye-Laws	3	
	—	41
		1279
Number of Foreign Members and Foreign Correspondents, December 31st, 1921	65	
Deduct 3 Foreign Members deceased and 2 Foreign Correspondents deceased	5	
	60	
	—	60
		1339

Deceased Fellows.

Compounders (9).

Beale, Sir William P. [elected in 1865].
Branner, J. C. [el. 1898].
Dickinson, T. L. [el. 1873].
Eaton, E. M. [el. 1894].
Fox, H. [el. 1887].
Hitchcock, Rev. G. S. [el. 1920].
Ross, C. A. [el. 1869].
Spencer, J. W. W. [el. 1877].
Sticht, C. R. [el. 1909].

Contributing Fellows (15).

Andrews, Rev. W. R. [elected in 1883].
Booth, W. H. [el. 1909].
Boulger, G. S. [el. 1875].
Carruthers, W. [el. 1867].
Gibbons, A. J. F. [el. 1917].
Gordon, Rev. J. M. [el. 1888].
Herbert, H. P. [el. 1919].
Herdman, W. [el. 1888].
Hilton, T. W. [el. 1873].
Jack, R. Logan [el. 1870].
Mansfield, F. T. [el. 1920].
Preumont, G. F. J. [el. 1913].
Robertson, T. E. [el. 1905].
Swinney, L. A. E. [el. 1908].
Westlake, E. [el. 1879].

FELLOWS RESIGNED (14).

Ashmore, G. P.
Fox, W. S.
Green, J. S.
Greenwell, A.
Gregson, W.
Jarvis, J. W.
Jordan, H. K. [since re-instated].
Perkins, H. I.
Platt, S. S.
Ross, P.
Sherborn, C. D.
Taylor, E. O.
Tyndale, W. C.
Woodruffe-Peacock, Rev. E. A.

FELLOWS REMOVED (3).

Dickson, Ernest.
Maitland, A. G.
Samuel, W. W.

FELLOWS ELECTED (84).

Abraham, W. E. V.
Adams, M. T.
Bagshawe, T. W.
Barber, C. T.
Batchelor, E.
Blake, G. S.
Bleeck, R.
Blizard, J. H.
Bond, A.
Bourchier, J. R.
Bradshaw, H. E.
Brown, E. E. S.
Bull, E. M.
Burchell, J. P. T.
Button, G. T.
Clayton, C. H. J.
Clift, S. G.
Cotton, L. A.
Coulson, A. L.
Cousins, W. J.
Cox, L. R.
Cronshaw, H. B.
Davies, E. L.
Day, H.
Dodd, F. H.
Double, I. S.
Doyle, R. G.
Edwards, W. N.
Engleheart, F. H. A.
Garnett, C. S.
Gell, H. M.
Gibby, D.
Goodyear, Miss E.
Gossling, F.
Hall, S.
Hallissy, T.
Haworth, H. C.
Henderson, J. McC.
Hollingworth, S. E.
Hughes, G. A.
Hunter, G. S.
Johnston, G.
Johnstone, J.
Kane, J.
Knaggs, Miss I. E.
Lovatt, A.

FELLOWS ELECTED (*cont.*).

Lowe, Miss I. H.
McDonald, Miss A. I.
Macmillan, W. E. F.
Mainprize, S. L.
Mitchell, G.
Mitchell, J.
Overy, Rev. C.
Ower, L. H.
Parker, Hon. H. L.
Parker, W. R.
Perkins, C. H.
Phillips, C. A.
Pilcher, C. F.
Platt, J. I.
Plowman, G. H.
Pollock, C. M.
Poxon, W.
Robling, G.
Russ, W.
Sandford, K. S.
Sands, H. H.
Scott, G. N.
Steers, J. A.
Stonehouse, T. H.
Stopes, M. C. C.
Sweeting, G. S.
Templeton, J. C.
Tilley, C. E.
Torrance, W.
Tyrrell, E. B.
Vachell, E. T.
Walker, W. S.
Walton, J. W.
Watson, D. M. S.
Winter, W. P.
Wood, Miss H. M.
Wooldridge, S. W.
Wrathall, L. L.

FOREIGN MEMBERS DECEASED (3).

Capellini, S. C. G. [elected in 1884].
Issel, A. [el. 1907].
Reusch, H. [el. 1897].

FOREIGN CORRESPONDENTS DECEASED (2).

Liebisch, T. [elected in 1899].
Weinschenk, E. H. [el. 1912].

After the Reports had been read, it was resolved :—

That they be received and entered on the Minutes of the Meeting, and that such parts of them as the Council shall think fit be printed and circulated among the Fellows.

It was afterwards resolved :—

That the thanks of the Society be given to Prof. E. J. Garwood and Dr. G. T. Prior, retiring from the office of Vice-President (and also from the Council) ; and to Dr. F. A. Bather, Mr. T. C. Cantrill, and Mr. J. F. N. Green, retiring from the Council.

After the Balloting-Glasses had been closed, and the Lists examined by the Scrutineers, the following gentlemen were declared to have been duly elected as the Officers and Council for the ensuing year :—

OFFICERS AND COUNCIL.—1923.

PRESIDENT.

Prof. Albert Charles Seward, Sc.D., F.R.S., F.L.S.

VICE-PRESIDENTS.

John William Evans, C.B.E., D.Sc., LL.B., F.R.S.
Richard Dixon Oldham, F.R.S.
Herbert Henry Thomas, M.A., Sc.D.
Prof. William Whitehead Watts, LL.D., Sc.D., M.Sc., F.R.S.

SECRETARIES.

Walter Campbell Smith, M.C., M.A.
James Archibald Douglas, M.A., B.Sc.

FOREIGN SECRETARY.

Sir Archibald Geikie, O.M., K.C.B., D.C.L., LL.D., Sc.D., F.R.S.

TREASURER.

Robert Stansfield Herries, M.A.

COUNCIL.

Charles William Andrews, B.A., D.Sc., F.R.S.
Frederick Noel Ashcroft, M.A.
Prof. Percy George Hamnall Boswell, O.B.E., D.Sc.
Prof. William S. Boulton, D.Sc.
James Archibald Douglas, M.A., B.Sc.
Gertrude Lilian Elles, M.B.E., D.Sc.
John William Evans, C.B.E., D.Sc., LL.B., F.R.S.
John Smith Flett, O.B.E., M.A., LL.D., D.Sc., M.B., F.R.S.
Sir Archibald Geikie, O.M., K.C.B., D.C.L., LL.D., Sc.D., F.R.S.
Frederick Henry Hatch, O.B.E., Ph.D.
Robert Stansfield Herries, M.A.
Prof. Owen Thomas Jones, M.A., D.Sc.
William Bernard Robinson King, O.B.E., M.A.
William Dixon Lang, M.A., Sc.D.
Richard Dixon Oldham, F.R.S.
Prof. Sidney Hugh Reynolds, M.A., Sc.D.
Prof. Albert Charles Seward, Sc.D., F.R.S., F.L.S.
Walter Campbell Smith, M.C., M.A.
Sir Aubrey Strahan, K.B.E., Sc.D., LL.D., F.R.S.
Sir Jethro J. Harris Teall, M.A., D.Sc., LL.B., F.R.S.
Herbert Henry Thomas, M.A., Sc.D.
Prof. William Whitehead Watts, LL.D., Sc.D., M.Sc., F.R.S.
Henry Woods, M.A., F.R.S.

LIST OF

THE FOREIGN MEMBERS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1922.

Date of Election.	
1884.	Senatore Prof. Giovanni Capellini, *Bologna*. (*Deceased.*)
1886.	Prof. Gustav Tschermak, *Vienna*.
1891.	Prof. Charles Barrois, *Lille*.
1893.	Prof. Waldemar Christofer Brögger, *Christiania*.
1894.	Prof. Edward Salisbury Dana, *New Haven, Conn.* (*U.S.A.*).
1896.	Prof. Albert Heim, *Zürich*.
1897.	Dr. Hans Reusch, *Christiania*. (*Deceased.*)
1898.	Dr. Charles Doolittle Walcott, *Washington, D.C.* (*U.S.A.*).
1899.	Prof. Emanuel Kayser, *Munich*.
1899.	M. Ernest Van den Broeck, *Brussels*.
1900.	M. Gustave F. Dollfus, *Paris*.
1900.	Prof. Paul von Groth, *Munich*.
1901.	Dr. Alexander Petrovich Karpinsky, *Petrograd*.
1901.	Prof. Antoine François Alfred Lacroix, *Paris*.
1903.	Prof. Albrecht Penck, *Berlin*.
1903.	Prof. Anton Koch, *Budapest*.
1904.	Prof. Henry Fairfield Osborn, *New York* (*U.S.A.*).
1905.	Prof. Louis Dollo, *Brussels*.
1907.	Dr. Emil Ernst August Tietze, *Vienna*.
1907.	Commendatore Prof. Arturo Issel, *Genoa*. (*Deceased.*)
1908.	Prof. Bundjirô Kôtô, *Tokyo*.
1909.	Prof. Johan H. L. Vogt, *Trondhjem*.
1911.	Prof. Baron Gerard Jakob De Geer, *Stockholm*.
1911.	M. Emmanuel de Margerie, *Strasbourg*.
1912.	Prof. Marcellin Boule, *Paris*.
1913.	Prof. Johannes Walther, *Halle an der Saale*.
1914.	Prof. Friedrich Johann Becke, *Vienna*.
1914.	Prof. Thomas Chrowder Chamberlin, *Chicago, Ill.* (*U.S.A.*).
1914.	Prof. Franz Julius Lœwinson-Lessing, *Petrograd*.
1914.	Prof. Alexis Petrovich Pavlow, *Moscow*.
1914.	Prof. William Berryman Scott, *Princeton, N.J.* (*U.S.A.*).
1921.	Dr. Frank Wigglesworth Clarke, *Washington, D.C.* (*U.S.A.*).
1921.	Prof. Émile Haug, *Paris*.
1921.	Prof. Maurice Lugeon, *Lausanne*.
1921.	Prof. Hans Schardt, *Zürich*.
1921.	Dr. Jakob Johannes Sederholm, *Helsingfors*.
1921.	Dr. Henry Stephens Washington, *Washington, D.C.* (*U.S.A.*).

LIST OF

THE FOREIGN CORRESPONDENTS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1922.

Date of Election.

1889. Dr. Rogier Diederik Marius Verbeek, *The Hague.*
1898. Dr. W. H. Dall, *Washington, D.C.* (*U.S.A.*).
1899. Dr. Gerhard Holm, *Stockholm.*
1900. Prof. Federico Sacco, *Turin.*
1902. Dr. Thorvaldr Thoroddsen, *Copenhagen.*
1904. Dr. Erich Dagobert von Drygalski, *Charlottenburg.*
1904. Prof. Giuseppe de Lorenzo, *Naples.*
1904. The Hon. Frank Springer, *East Las Vegas, New Mexico* (*U.S.A.*).
1906. Prof. John M. Clarke, *Albany, N.Y.* (*U.S.A.*).
1906. Prof. William Morris Davis, *Cambridge, Mass.* (*U.S.A.*).
1909. Dr. Daniel de Cortázar, *Madrid.*
1911. Prof. Arvid Gustaf Högbom, *Upsala.*
1911. Prof. Charles Depéret, *Lyons.*
1912. Dr. Whitman Cross, *Washington, D.C.* (*U.S.A.*).
1912. Baron Francis Nopcsa, *Vienna.*
1912. Prof. Karl Diener, *Vienna.*
1912. Prof. Fusakichi Omori, *Tokyo.*
1913. Dr. Per Johan Holmquist, *Stockholm.*
1921. Prof. Lucien Cayeux, *Paris.*
1921. Dr. Maurice Cossmann, *Paris.*
1921. Prof. Henry de Dorlodot, *Louvain.*
1921. Prof. Henri Douvillé, *Paris.*
1921. Prof. Louis Duparc, *Geneva.*
1921. Prof. Johan Kiær, *Christiania.*
1921. Prof. Waldemar Lindgren, *Boston, Mass.* (*U.S.A.*).
1921. Prof. John J. Stevenson, *New York City* (*U.S.A.*).

[Note.—The Lists of Awards of Medals and Funds, up to the year 1907 inclusive, are published in the 'History of the Geological Society.']

AWARDS OF THE WOLLASTON MEDAL

UNDER THE CONDITIONS OF THE 'DONATION FUND,'

ESTABLISHED BY

WILLIAM HYDE WOLLASTON, M.D., F.R.S., F.G.S., etc.

'To promote researches concerning the mineral structure of the Earth, and to enable the Council of the Geological Society to reward those individuals of any country by whom such researches may hereafter be made,'—'such individual not being a Member of the Council.'

1908. Prof. Paul von Groth.
1909. Mr. Horace B. Woodward.
1910. Prof. William B. Scott.
1911. Prof. Waldemar C. Brögger.
1912. Sir Lazarus Fletcher.
1913. The Rev. Osmond Fisher.
1914. Prof. John Edward Marr.
1915. Sir T. W. Edgeworth David.
1916. Dr. A. P. Karpinsky.
1917. Prof. A. F. A. Lacroix.
1918. Dr. Charles D. Walcott.
1919. Sir Aubrey Strahan.
1920. Prof. G. J. De Geer.
1921. { Dr. B. N. Peach. Dr. John Horne.
1922. Dr. Alfred Harker.
1923. Mr. William Whitaker.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE WOLLASTON 'DONATION FUND.'

1908. Dr. Herbert Henry Thomas.
1909. Mr. Arthur J. C. Molyneux.
1910. Mr. Edward B. Bailey.
1911. Prof. Owen Thomas Jones.
1912. Mr. Charles Irving Gardiner.
1913. Mr. William Wickham King.
1914. Mr. R. Bullen Newton.
1915. Mr. Charles Bertie Wedd.
1916. Mr. William Bourke Wright.
1917. Prof. Percy G. H. Boswell.
1918. Mr. Albert Ernest Kitson.
1919. Dr. A. L. Du Toit.
1920. Mr. William B. R. King.
1921. Dr. Thomas O. Bosworth.
1922. Dr. Leonard J. Wills.
1923. Mr. Harold Herbert Read.

AWARDS OF THE MURCHISON MEDAL

UNDER THE CONDITIONS OF THE

'MURCHISON GEOLOGICAL FUND,'

ESTABLISHED UNDER THE WILL OF THE LATE

SIR RODERICK IMPEY MURCHISON, Bart., F.R.S., F.G.S.

'To be applied in every consecutive year, in such manner as the Council of the Society may deem most useful in advancing Geological Science, whether by granting sums of money to travellers in pursuit of knowledge, to authors of memoirs, or to persons actually employed in any enquiries bearing upon the science of Geology, or in rewarding any such travellers, authors, or other persons, and the Medal to be given to some person to whom such Council shall grant any sum of money or recompense in respect of Geological Science.'

1908. Prof. Albert Charles Seward.
1909. Prof. Grenville A. J. Cole.
1910. Prof. Arthur P. Coleman.
1911. Mr. Richard Hill Tiddeman.
1912. Prof. Louis Dollo.
1913. Mr. George Barrow.
1914. Mr. William A. E. Ussher.
1915. Prof. William W. Watts.
1916. Dr. Robert Kidston.
1917. Dr. George F. Matthew.
1918. Mr. Joseph Burr Tyrrell.
1919. Miss Gertrude L. Elles.
1920. Dame E. M. R. Shakespear.
1921. Mr. Edgar Sterling Cobbold.
1922. Dr. John William Evans.
1923. Prof. John Joly.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE

'MURCHISON GEOLOGICAL FUND.'

1908. Miss Ethel Gertrude Skeat.
1909. Dr. James Vincent Elsden.
1910. Mr. John Walker Stather.
1911. Mr. Edgar Sterling Cobbold.
1912. Dr. Arthur Morley Davies.
1913. Mr. Ernest E. L. Dixon.
1914. Mr. Frederick Nairn Haward.
1915. Mr. David Cledlyn Evans.
1916. Mr. George Walter Tyrrell.
1917. Dr. William Mackie.
1918. Mr. Thomas Crook.
1919. Mrs. Eleanor Mary Reid.
1920. Dr. David Woolacott.
1921. Dr. Albert Gilligan.
1922. Dr. Herbert Bolton.
1923. Mr. T. H. Withers.

AWARDS OF THE LYELL MEDAL

UNDER THE CONDITIONS OF THE

'LYELL GEOLOGICAL FUND,

ESTABLISHED UNDER THE WILL AND CODICIL OF THE LATE

SIR CHARLES LYELL, Bart., F.R.S., F.G.S.

The Medal 'to be cast in bronze and to be given annually' (or from time to time) 'as a mark of honorary distinction and as an expression on the part of the governing body of the Society that the Medallist (who may be of any country or either sex) has deserved well of the Science,'—'not less than one third of the annual interest [of the fund] to accompany the Medal, the remaining interest to be given in one or more portions, at the discretion of the Council, for the encouragement of Geology or of any of the allied sciences by which they shall consider Geology to have been most materially advanced, either for travelling expenses or for a memoir or paper published, or in progress, and without reference to the sex or nationality of the author, or the language in which any such memoir or paper may be written.'

There is a further provision for suspending the award for one year, and in such case for the awarding of a Medal to 'each of two persons who have been jointly engaged in the same exploration in the same country, or perhaps on allied subjects in different countries, the proportion of interest always not being less to each Medal than one third of the annual interest.'

1908. Mr. Richard Dixon Oldham.
1909. Prof. Percy Fry Kendall.
1910. Dr. Arthur Vaughan.
1911. { Dr. Francis Arthur Bather.
Dr. Arthur Walton Rowe. }
1912. Mr. Philip Lake.
1913. Mr. Sydney S. Buckman.
1914. Mr. Charles S. Middlemiss.
1915. Prof. Edmund J. Garwood.
1916. Dr. Charles W. Andrews.
1917. Dr. Wheelton Hind.
1918. Mr. Henry Woods.
1919. Dr. William Fraser Hume.
1920. Dr. Edward Greenly.
1921. M. E. de Margerie.
1922. Dr. Charles Davison.
1923. M. Gustave F. Dollfus.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE 'LYELL GEOLOGICAL FUND.'

1908. Prof. T. Franklin Sibly.
1908. Mr. H. J. Osborne White.
1909. Mr. H. Brantwood Maufe.
1909. Mr. Robert G. Carruthers.
1910. Dr. F. R. Cowper Reed.
1910. Dr. Robert Broom.
1911. Prof. Charles Gilbert Cullis.
1912. Dr. Arthur R. Dwerryhouse.
1912. Mr. Robert Heron Rastall.
1913. Mr. Llewellyn Treacher.
1914. The Rev. Walter Howchin.
1914. Mr. John Postlethwaite.
1915. Mr. John Parkinson.
1915. Dr. Lewis Moysey.
1916. Mr. Martin A. C. Hinton.
1916. Mr. Alfred S. Kennard.
1917. Prof. A. Hubert Cox.
1917. Mr. Tressilian C. Nicholas.
1918. Mr. Vincent Charles Illing.
1918. Mr. William Kingdon Spencer.
1919. Mr. John Pringle.
1919. Dr. Stanley Smith.
1920. Dr. John D. Falconer.
1920. Mr. Ernest S. Pinfold.
1921. Dr. Herbert L. Hawkins.
1921. Mr. C. E. N. Bromehead.
1922. Mr. Arthur Macconochie.
1922. Mr. David Tait.
1923. Prof. W. N. Benson.
1923. Prof. W. T. Gordon.

AWARDS OF THE BIGSBY MEDAL,

FOUNDED BY THE LATE

DR. J. J. BIGSBY, F.R.S., F.G.S.

To be awarded biennially 'as an acknowledgment of eminent services in any department of Geology, irrespective of the receiver's country; but he must not be older than 45 years at his last birthday, thus probably not too old for further work, and not too young to have done much.'

1909. Dr. John Smith Flett.
1911. Prof. Othenio Abel.
1913. Sir Thomas H. Holland.
1915. Sir Henry Hubert Hayden.
1917. Mr. Robert G. Carruthers.
1919. Sir Douglas Mawson.
1921. Dr. Lewis L. Fermor.
1923. Mr. E. B. Bailey.

AWARDS OF THE PRESTWICH MEDAL,

ESTABLISHED UNDER THE WILL OF THE LATE

SIR JOSEPH PRESTWICH, F.R.S., F.G.S.

'To apply the accumulated annual proceeds . . . at the end of every three years, in providing a Gold Medal of the value of Twenty Pounds, which, with the remainder of the proceeds, is to be awarded . . . to the person or persons, either male or female, and either resident in England or abroad, who shall have done well for the advancement of the science of Geology; or, from time to time to accumulate the annual proceeds for a period not exceeding six years, and apply the said accumulated annual proceeds to some object of special research bearing on Stratigraphical or Physical Geology, to be carried out by one single individual or by a Committee; or, failing these objects, to accumulate the annual proceeds for either three or six years, and devote such proceeds to such special purposes as may be decided.'

1909. Lady (John) Evans.
1912. Library extension.
1915. Prof. Émile Cartailhac.
1918. Sir William Boyd Dawkins.
1921. List of Geological Literature.

AWARDS OF THE PROCEEDS OF THE BARLOW-JAMESON FUND,

ESTABLISHED UNDER THE WILL OF THE LATE

DR. H. C. BARLOW, F.G.S.

'The perpetual interest to be applied every two or three years, as may be approved by the Council, to or for the advancement of Geological Science.'

1908. 'Grey-Wether' sarsens on Marlborough Downs.
1911. Mr. John Frederick Norman Green.
1913. {Mr. Bernard Smith. / Mr. John Brooke Scrivenor.
1915. Mr. Joseph G. Hamling.
1917. Mr. Henry Dewey.
1921. List of Geological Literature.

AWARDS OF THE PROCEEDS OF THE 'DANIEL-PIDGEON FUND,'

FOUNDED BY MRS. PIDGEON, IN ACCORDANCE WITH THE WILL OF THE LATE

DANIEL PIDGEON, F.G.S.

"An annual grant derivable from the interest on the Fund, to be used at the discretion of the Council, in whatever way may in their opinion best promote Geological Original Research, their Grantees being in all cases not more than twenty-eight years of age.'

1908. Mr. James A. Douglas.
1909. Dr. Alexander M. Finlayson.
1910. Mr. Robert Boyle.
1911. Mr. Tressilian C. Nicholas.
1912. Mr. Otway H. Little.
1913. Mr. Roderick U. Sayce.
1914. Prof. Percy G. H. Boswell.
1915. Mr. E. Talbot Paris.
1916. Dr. John K. Charlesworth.
1917. Dr. Arthur Holmes.
1918. Mr. James A. Butterfield.
1920. Miss M. E. J. Chandler.
1920. Dr. L. Dudley Stamp.
1921. Mr. Ralph W. Segnit.
1921. Mr. Frederick S. Wallis.
1922. Mr. H. Price Lewis.
1923. Mr. Howel Williams.

Estimates for

INCOME EXPECTED.

	£	s.	d.	£	s.	d.
Compositions	157	10	0			
Admission-Fees, 1923	453	12	0			
				611	2	0
Arrears of Annual Contributions	150	0	0			
Annual Contributions, 1923	2240	0	0			
Annual Contributions in advance	80	0	0			
				2470	0	0
Quarterly Journal Subscriptions	240	0	0			
List of Geol. Lit. Subscriptions	25	0	0			
				265	0	0
Sale of the Quarterly Journal, including Longmans' Account				300	0	0
Sale of other Publications				15	0	0
Miscellaneous Receipts				40	0	0
Interest on Deposit-Account				7	10	0
Dividends on £2500 India 3 per cent. Stock	75	0	0			
Dividends on £300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	15	0	0			
Dividends on £2250 London & North-Western Railway 4 per cent. Preference Stock	90	0	0			
Dividends on £2800 London & South-Western Railway 4 per cent. Consolidated Preference Stock	112	0	0			
Dividends on £2072 Midland Railway $2\frac{1}{2}$ per cent. Perpetual Preference Stock	51	16	0			
Dividends on £267 6*s*. 7*d*. Natal 3 per cent. Stock.	8	0	4			
				351	16	4
				£4060	8	4

	£	s.	d.
Balance in hand, January 1st, 1923	167	13	2
Income of Sorby and Hudleston Bequests	70	0	0
Deficit	238	5	1
	£4536	6	7

the Year 1923.

EXPENDITURE ESTIMATED.

	£	s.	d.	£	s.	d.
Repairs and Maintenance Fund				250	0	0
House-Expenditure:						
Taxes and Insurance	25	0	0			
Electric Lighting	50	0	0			
Gas	30	0	0			
Fuel	50	0	0			
Annual Cleaning	20	0	0			
Washing and Sundry Expenses	70	0	0			
Tea at Meetings	25	0	0			
				270	0	0
Salaries and Wages, etc.				1450	0	0
Office-Expenditure:						
Stationery	50	0	0			
Miscellaneous Printing	110	0	0			
Postages and Sundry Expenses	100	0	0			
				260	0	0
Grant to Conjoint Board of Scientific Societies				5	0	0
Library (Books and Binding)	150	0	0			
(Catalogue Cards)	5	0	0			
				155	0	0
Publications:						
Quarterly Journal (Vol. lxxix)	1000	0	0			
Postage on Journal, Addressing, etc.	40	0	0			
Abstracts of Proceedings, including Postage	240	0	0			
List of Geological Literature for 1922	160	0	0			
				1440	0	0
				£3830	0	0

List of Geological Literature for 1914: Balance of Printing Account.	£156	6	7
List of Geological Literature for 1915–19: Printing Account (estimated).	£550	0	0
	£4536	6	7

ROBERT S. HERRIES, *Treasurer.*

January 30th, 1923.

RECEIPTS.

	£	s.	d.	£	s.	d.
To Balance in the hands of the Bankers at January 1st, 1922:						
Current Account	71	3	9			
,, Balance in the hands of the Clerk at January 1st, 1922	3	2	5			
				74	6	2
,, Compositions				210	0	0
,, Admission-Fees:						
Arrears	69	6	0			
Current	415	16	0			
				485	2	0
,, Arrears of Annual Contributions				152	5	0
,, Annual Contributions for 1922	2173	2	6			
,, Annual Contributions in advance	77	14	0			
				2250	16	6
,, Publications:						
Sale of Quarterly Journal:						
,, Vols. i to lxxvii (less Commission £27 14*s.* 0*d.*)	282	3	1			
,, Vol. lxxviii (less Commission £6 4*s.* 1*d.*)	35	15	0			
,, Other Publications (less Commission)	16	15	10			
				334	13	11
,, Quarterly Journal Subscriptions	242	6	0			
,, List of Geol. Lit. Subscriptions	27	2	6			
				269	8	6
,, Miscellaneous Receipts				40	7	1
,, Interest on Deposit				12	0	6
,, Dividends, as received:—						
£2500 India 3 per cent. Stock	75	0	0			
£300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	10	13	9			
£2250 London & North-Western Railway 4 per cent. Preference Stock	64	2	6			
£2800 London & South-Western Railway 4 per cent. Consolidated Preference Stock	79	16	0			
£2072 Midland Railway 2½ per cent. Perpetual Preference Stock	37	4	7			
£267 6*s.* 7*d.* Natal 3 per cent. Stock	5	16	4			
				272	13	2
,, Income-Tax recovered				83	1	0

Special Receipts.

	£	s.	d.	£	s.	d.
To Transfer from Sorby & Hudleston Bequests.	75	6	2			
,, Grant from the Royal Society	100	0	0			
				175	6	2
				£4360	0	0

Year ended December 30th, 1922.

PAYMENTS.

	£	s.	d.	£	s.	d.
By Maintenance Fund				150	0	0
,, House-Expenditure:						
Taxes		15	0			
Fire- and other Insurance	24	0	5			
Electric Lighting	49	11	8			
Gas	18	18	6			
Fuel	46	5	6			
Furniture and Repairs		10	6			
Annual Cleaning	16	2	0			
Washing and Sundry Expenses	68	8	11			
Tea at Meetings	19	18	7			
				244	11	1
,, Salaries and Wages, etc.:						
Permanent Secretary	550	0	0			
Librarian	300	0	0			
Clerk	200	0	0			
Junior Assistant	127	5	0			
House-Porter and Wife	144	0	9			
Housemaid	76	9	10			
Charwoman and Occasional Assistance	36	2	0			
Accountants' Fee	10	10	0			
				1444	7	7
,, Office-Expenditure:						
Stationery	44	2	0			
Miscellaneous Printing	109	6	2			
Postages and Sundry Expenses	96	7	9			
				249	15	11
,, Library:						
Books and Binding	123	17	0			
Catalogue Cards	6	18	0			
				130	15	0
,, Publications:						
Quarterly Journal, Vol. lxxviii, Paper, Printing, and Illustrations	1082	5	3			
Postage on Journal, Addressing, etc.	27	19	2			
Abstracts, including Postage	231	1	11			
List of Geological Literature for 1921	167	15	11			
				1509	2	3
,, Grant to the Conjoint Board of Scientific Societies (1922)				10	0	0
,, List of Fellows				68	5	0
Special Expenditure.						
By List of Geological Literature for 1914, Printing, on a/c	100	0	0			
,, ,, ,, ,, for 1914, Compilation...	10	10	0			
,, ,, ,, ,, for 1915–19, Balance of Compilation	275	0	0			
				385	10	0
By Balance in the hands of the Bankers at December 30th, 1922	149	9	1			
,, Balance in the hands of the Clerk at December 30th, 1922	18	4	1			
				167	13	2
				£4360	0	0

We have compared this Statement with the Books and Accounts presented to us, and find them to agree.

F. N. ASHCROFT, } *Auditors.*
R. M. DEELEY, }

January 30th, 1923.

ROBERT S. HERRIES, *Treasurer.*

Statement of Trust-Funds and Special Funds: December 30th, 1922.

'Wollaston Donation Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1922	32	3	8	By Cost of Medal	10	10	0
,, Dividends on the Fund invested in £1073 Hampshire County 3 per cent. Stock	32	3	8	,, Award from the Balance of the Fund	21	13	8
				,, Balance at the Bankers' at December 30th, 1922	32	3	8
	£64	7	4		£64	7	4

'Murchison Geological Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1922	26	0	3	By Cost of Medal	1	1	6
,, Dividends (less Income-Tax) on the Fund invested in £1334 London & North-Western Railway 3 per cent. Debenture Stock	28	10	3	,, Award to the Medallist......	10	10	0
,, Income Tax recovered	12	0	2	,, Award from the Balance of the Fund	28	8	10
				,, Balance at the Bankers' at December 30th, 1922	26	10	4
	£66	10	8		£66	10	8

'Lyell Geological Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1922	52	15	3	By Cost of Medal	1	5	6
,, Dividends on the Fund invested in £2010 1*s.* 0*d.* Metropolitan $3\frac{1}{2}$ per cent. Stock	70	7	0	,, Award to the Medallist......	25	0	0
				,, Awards from the Balance of the Fund	44	1	6
				,, Balance at the Bankers' at December 30th, 1922	52	15	3
	£123	2	3		£123	2	3

'Barlow-Jameson Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1922......	9	2	6	By Balance at the Bankers' at December 30th, 1922	23	6	10
,, Dividends (less Income-Tax) on the Fund invested in £468 Great Northern Railway 3 per cent. Debenture Stock	10	0	2				
,, Income Tax recovered......	4	4	2				
	£23	6	10		£23	6	10

‘Bigsby Fund.’ Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1922	4	1	11	By Balance at the Bankers' at December 30th, 1922	10	11	1
,, Dividends (less Income-Tax) on the Fund invested in £210 Cardiff 3 per cent. Stock	4	11	4				
,, Income Tax recovered	1	17	10				
	£10	11	1		£10	11	1

‘Geological Relief Fund.’ Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1922	70	1	0	By Grants	4	4	0
,, Dividends on the Fund invested in £139 3*s.* 7*d.* India 3 per cent. Stock	4	3	4	,, Balance at the Bankers' at December 30th, 1922	70	17	3
,, Interest on Deposit		16	11				
	£75	1	3		£75	1	3

‘Prestwich Trust Fund.’ Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1922	15	15	0	By Balance at the Bankers' at December 30th, 1922	36	15	0
,, Dividends on the Fund invested in £700 India 3 per cent. Stock	21	0	0				
	£36	15	0		£36	15	0

‘Daniel-Pidgeon Fund.’ Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1922	15	5	8	By Awards	30	11	4
,, Dividends on the Fund invested in £1019 1*s.* 2*d.* Bristol Corporation 3 per cent. Stock	30	11	4	,, Balance at the Bankers' at December 30th, 1922	15	5	8
	£45	17	0		£45	17	0

'Gloyne Outdoor Geological Research Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Amount received from the Trustees of the Estate of Charles Papps Gloyne	1275	12	5	By Purchase of £1676 17*s.* 6*d.* 3½ per cent. Conversion Loan (1961)	1284	0	2
,, Interest on Deposit	8	7	9	,, Balance at the Bankers' at December 30th, 1922	22	0	2
,, Dividend (less Income-Tax) on the Fund invested in £1676 17*s.* 6*d.* 3½ per cent. Conversion Loan (1961) for half-year	22	0	2				
	£1306	0	4		£1306	0	4

SPECIAL FUNDS.

Sorby and Hudleston Bequests. (£1000 Stock each.)

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1922	1	14	0	By Transfer to General Purposes Account	75	6	2
,, Dividends (less Income-Tax) on the Fund invested in £2000 Canada 3½ per cent. Stock	50	15	0				
,, Income Tax recovered	22	17	2				
	£75	6	2		£75	6	2

Maintenance Fund.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1922	137	9	0	By Payments during the year	88	19	2
,, Transfer from General Purposes Account	150	0	0	,, Balance at the Bankers' at December 30th, 1922	202	3	11
,, Interest on Deposit	3	14	1				
	£291	3	1		£291	3	1

We have compared this Statement with the Books and Accounts presented to us, and find them to agree.

ROBERT S. HERRIES, *Treasurer.*

F. N. ASHCROFT,
R. M. DEELEY, } *Auditors.*

January 30th, 1923.

Statement relating to the Society's Property.

December 30th, 1922.

	£ s. d.	£ s. d.
Balance in the Bankers' hands, December 30th, 1922	149 9 1	
Balance in the Clerk's hands, December 30th, 1922	18 4 1	
		167 13 2
Balance of the Maintenance Fund		202 3 11
Arrears of Annual Contributions (Estimated to produce £150 0*s.* 0*d.*)		284 1 0
		£653 18 1

Funded Property:—	Cost Price.	Valued at Dec. 30th, 1922.
£2500 India 3 per cent. Stock	2623 19 0	1375 0 0
£300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	502 15 3	291 0 0
£2250 London & North-Western Railway 4 per cent. Preference Stock	2898 10 6	1788 15 0
£2800 London & South-Western Railway 4 per cent. Consolidated Preference Stock	3607 7 6	2198 0 0
£2072 Midland Railway 2½ per cent. Perpetual Preference Stock	1850 19 6	1025 12 10
£267 6*s.* 7*d.* Natal 3 per cent. Stock	250 0 0	187 2 7
£2000 Canada 3½ per cent. Stock [1930–1950] (Sorby and Hudleston Bequests)	1982 11 0	1560 0 0
	£13,716 2 9	£8425 10 5

[NOTE.—*The above amount does not include the value of the Library, Furniture, and stock of unsold Publications.*]

ROBERT S. HERRIES, *Treasurer*

January 30th, 1923

Award of the Wollaston Medal.

In presenting the Wollaston Medal to Mr. William Whitaker, F.R.S., the President addressed him as follows:—

Mr. Whitaker,—

The award to you of the Wollaston Medal expresses, with the greatest emphasis that is possible, not only the high value which is placed upon your contributions to Geology, but the affection with which you are regarded by the Society as a whole. The nature and worth of your researches in many parts of England were dealt with by Presidents much better qualified for the task than I am, when you received the Murchison Medal in 1886 and the Prestwich Medal in 1906. It is a privilege which I value very highly to be in a position to give to you the blue ribbon of British Geology, and in handing it to you I venture to lay stress upon what I may call the more human aspect of your services to Geology. There is a genius of the heart as well as of the brain; and, if I may say so, you are fortunate in possessing both. Familiar, in a limited degree, with the more technical side of your work, I have long been accustomed to think of you as an exceptionally happy illustration of the truth of the dictum that men of science are always the most human. It is no light service that you have rendered through your sympathetic appreciation of the needs and aspirations of younger generations of students, both professional and amateur, by imparting to them some of your own enthusiasm, enabling them to acquire not only a love of Nature and the joy of probing into the secrets of the rocks, but the ability to realize the truth of W. E. Henley's lines:—

> 'What Nature has writ with her lusty wit
> Is worded so wisely and kindly,
> That whoever has dipped in her manuscript
> Must up and follow her blindly.'

Mr. Whitaker replied in the following words:—

Mr. President,—

I am proud to find my name associated with the names of the ninety-four good men, from William Smith onward, who have received this medal.

Looking back over many years' work at Geology, I am glad to bear witness to the great advantage that I have reaped from the work of those who have gone before me, and to acknowledge the great help that I have received from the many living workers in the various branches of our science, among whom I have spent the greater part of my life. Old and young, I thank them all.

Should what work I have done be of like service to those who follow me, I shall not have lived in vain.

It is one of the most pleasing prospects of old age to see that there are younger men able and willing to take up the work which we older men have to drop, and, looking around me, I salute the Medallists of the future.

Since my retirement from the Geological Survey, more than a quarter of a century ago, my work has, of necessity, been largely limited to applications of our science to more or less practical purposes. In this I have been associated with chemists, engineers, and others, from whom I have learnt much as to the bearings of various sciences on each other, and whose help I am glad to acknowledge. To the continuance of this help I am still looking forward.

I thank the Council for this, the third Medal which it has awarded to me. I thank you, Sir, for the very kind words with which you have given me the Medal, and I thank all my friends for the way in which they have marked their approval of the award.

Award of the Murchison Medal.

The President then presented the Murchison Medal to Prof. John Joly, F.R.S., addressing him as follows:—

Dr. Joly,—

It is with peculiar pleasure that I hand the Murchison Medal to a Professor and Fellow of Trinity College, Dublin—a foundation for which, not only as in private duty bound as an honorary graduate, but also on other grounds, I have an affection. Your contributions to science have been many and varied: at once a physicist and a geologist, you have by your researches happily united the two sciences, and in so doing you have displayed unceasing industry, remarkable fertility for invention, elegance in

experimentation, and brilliance in interpretation. Incidentally, I may add that botanists also owe you a debt of gratitude for the distinguished part that you played, in conjunction with Prof. H. H. Dixon, in contributing to our knowledge of the ascent of sap in trees. The publication of your work on 'Radioactivity and Geology' marks an epoch in the history of our science. By your quantitative determination of the distribution of radium and, later, thorium, you were able to liberate Geology from the narrow limits of time imposed upon it by inadequate knowledge. Your investigation of the mysterious haloes of biotite and other minerals is a model of scientific research: in its later stages it afforded unexpected evidence of a change of rate in the disintegration of uranium dependent on time. At an earlier date you attacked the problem of the Earth's age by another method of investigation, with results not inconsistent with your latest estimate. You have greatly extended the use of the microscope as an instrument of scientific research; by an original method you have measured the expansion which rocks undergo on fusion, using for observation minute spherules of material not contained in an enclosing vessel. That you still take a keen interest in geological problems is shown by your recent suggestion of a *vera causa* for the movements of the land imagined by Wegener.

It is not often that one finds in combination powers of imagination such as you possess, and sufficient patience and critical faculty to exercise the necessary control; nor are there many scientific men who are able, as you are, to express the results of research in language which is also literature.

Prof. Joly replied in the following words:—

Mr. President,—

I find it difficult to express how much I feel the honour that you, Sir, and the Council of this Society have conferred upon me in awarding to me the Murchison Medal. I am sincere when I say that I never anticipated so great a distinction.

I have—so far as I was able—consistently worked in that domain of science where Geology and Physics meet. Drawn into physical lines of thought by early training and associations, I have always looked with a certain longing at that delightful aspect of the geologist's mission which leads him to the field and to the

mountain to study the rocks as Nature made them. In my youth I spent many years in the Swiss Alps: Nature in her most impressive developments was around me. Yet, while I revelled in the beauty of that geologist's paradise, I felt with a certain regret that my contact with it must be, not among the mountains, but through the work of the laboratory.

But now, Sir, receiving this Medal and knowing that it means recognition from so many eminent geologists, I ask myself whether, after all, I did not do right. True, I cannot shake off the feeling that I am very ignorant of much that is known to the worker in the field. But then, Sir, the approval of this great Society encourages me to hope that something may remain of my poor work, which others will be able to apply to the revelations of Nature.

Radioactivity, for instance, has been born in our time. I believe that the day is near when the bearing of this branch of science on Geology will be so far recognized that labour expended in investigating the interaction of the two sciences will not be regarded as wasted. Most ideas are, however, born to perish, some living a little longer than others, but in the end being obliterated by the denuding forces of Time. There are many who regard the present as a period of revolution and diastrophism for our science. But we need have no fears: new ideas will assuredly take the place of the old.

I have to thank you, Sir, and the Council and the Fellows of this Society for encouragement and renewed hopefulness.

Award of the Lyell Medal.

In presenting the Lyell Medal to M. Gustave F. Dollfus, For.Memb.G.S., the President addressed him as follows:—

Monsieur Dollfus,—

Though political frontiers may sometimes coincide with natural boundaries on the surface, the deeper strata form connecting-links, not only between different parts of Europe, but between our own island and the neighbouring lands of France and Belgium. Geologists are necessarily divided into national groups, but their

researches are international: it is our pleasure, as well as our duty, to give expression to this aspect of Geology by the bestowal of some of our awards upon foreign colleagues. Over thirty years ago the Geological Society elected you a Foreign Correspondent, and twenty-three years ago it welcomed you as a Foreign Member: to-day we give a further proof of our appreciation of your services, and of our desire to mark the persistence of the ties of friendship between French and British geologists, by presenting to you the Lyell Medal.

It is more than half a century since you began your geological career—a career characterized by uninterrupted activity, which has not only brought its own reward in facts discovered and in the advancement of knowledge; you have also received many honours both at home and abroad. Your researches have been both intensive and extensive. You have made the Paris Basin your especial province, investigating the stratigraphy of its sediments, following the crustal movements and the changing geographical conditions; you also qualified yourself by acquiring an intimate knowledge of different groups of recent animals, in order to deal as an expert with its successive faunas. The Paris Basin is classic ground; to the geologist almost sacred ground: your name will always be associated with the interpretation of its secrets. You have also ranged over wider fields, utilizing facts of observation as a basis of philosophical deduction. On the more practical side you have rendered invaluable service as a maker of maps, and in demonstrating the economic value of a knowledge of the rocks. In 1906 you penetrated the strata below the English Channel, and showed that it was not geological difficulties that stood in the way of the construction of a tunnel, but political reasons, which, as you truly said, are 'étrangères à la question géologique.' Though apparently separate, France and England are united below the water. As Dr. Charles Barrois happily said, in a congratulatory Address from the University of Lille to our Society in 1907:—

'The University teaches her pupils that France and England, though separated only since yesterday by the waters of the Pas-de-Calais, have been joined for millions of years by the solid foundations of the Chalk.'

May the presentation of this Medal be regarded as the expression of a desire on our part to emphasize the deep-seated nature of the bonds between the two countries.

M. Dollfus replied in the following words:—

Monsieur le Président,

Vous voyez devant vous un homme bien embarrassé, il se demande en quelle langue il doit vous remercier; ce n'est pas un littérateur que vous avez bien voulu récompenser, mais un scientifique, et vous aurez de toutes manières à l'excuser, car il aurait tout autant de peine à vous exprimer en français qu'en anglais toute sa gratitude.

Il vous remercie de l'avoir choisi, malgré son âge, malgré son éloignement, et il n'attendait pas l'honneur que vous voulez bien lui faire comme un couronnement de sa carrière.

Ce n'est pas que les encouragements lui aient totalement manque jusqu'ici: il a déjà eu sa part, mais il trouve surtout sa récompense dans la pensée des découvertes qu'il a pu faire dans le domaine géologique et dans les contributions qu'il a pu apporter dans la stratigraphie et la paléontologie du Bassin de Paris et le Tertiaire français, qui depuis cinquante ans sont l'objet de ses recherches sur le terrain.

Les hommes de ma génération, qui ont débuté vers 1870, ont trouvé les traits généraux de la science géologique déjà tracés, et Lyell est parmi ceux qui ont le plus contribué à son établissement: ils se sont avancés avec assurance, guidés par la doctrine des causes actuelles de Lyell, comme par un phare lumineux qui ne pouvait les égarer. Les hommes de la génération qui m'a suivi durent travailler bien davantage pour découvrir des choses nouvelles; car la Science se complique de plus en plus, et demande des efforts toujours plus longs et plus obstinés. Mais c'est encore dans Lyell qu'ils trouvent le meilleur guide, nul plus que moi n'en a recommandé la lecture attentive aux débutants. Nul maître n'a eu de disciple plus fervent, et aucune récompense ne pouvait être mieux appropriée à un admirateur.

Je n'ai pu connaître Lyell personnellement, il est mort en 1875, l'année même où je suis venu pour la première fois étudier la géologie de l'Angleterre. Mais j'ai connu à Paris le vieux paléontologue Deshayes, qui l'avait aidé dans ses travaux et lui avait préparé les listes de fossiles qui l'ont conduit à établir les grandes divisions de l'Eocène, le Miocène et le Pliocène, lesquelles ont été universellement acceptées.

Je suis un arrière-petit-fils scientifique de Brongniart, l'un des fondateurs de la Géologie française, auquel avait succédé à la Sorbonne Constant Prévost, dont l'un des meilleurs élèves a été Jules

Gosselet dont je m'honore d'avoir été le disciple. La doctrine de Constant Prévost est bien celle de Lyell, celle des causes actuelles par opposition à celle des causes mystérieuses et inconnues contre laquelle il fallait alors lutter. Mais Constant Prévost en a tiré des conséquences de synchronisme exagéré que les études postérieures n'ont pas confirmées.

Pour les jeunes qui nous suivent, la lutte est ailleurs, elle est dans la théorie de la structure des montagnes et dans la possibilité de déplacement des masses minérales ; là encore il est probable qu'il y a exagération dans les deux sens, et que nous arriverons, sous l'égide de Lyell, à des conceptions définitives basées sur des constatations décisives. Merci, mes chers confrères, grand merci.

Award of the Bigsby Medal.

In handing the Bigsby Medal, awarded to Mr. Edward Battersby Bailey, M.C., to Mr. G. W. Lamplugh, F.R.S., for transmission to the recipient, the President addressed him as follows:—

Mr. Lamplugh,—

As a fellow-graduate of Mr. Bailey's University, I may venture to express the opinion that the work which he has done entitles him to a very honourable place in the list of Cambridge men who have added to academic distinction the greater distinction that is earned by successful labour in the field. Introduced to Scottish Geology by Dr. Peach, Mr. Bailey devoted himself mainly to the problems of tectonics and petrogenesis. In collaboration with C. T. Clough and H. B. Maufe, he greatly advanced our knowledge of the mechanism of plutonic intrusion by the study of the cauldron-subsidence of Glencoe. The Highlands of Scotland are famous in literature and in geology: the misty atmosphere of the glens is charged with memories which appeal to the imagination of the poet, and the structure of the rocks has long tried the ingenuity and temper of geologists. In 1910 Mr. Bailey enunciated a theory of recumbent folds in explanation of the structure of the Ballachulish district, and recently summarized the results of his researches in other regions in a masterly communication to this Society. His investigations have provided a stimulus which cannot fail to have far-reaching effects. As a soldier as well as a geologist,

Mr. Bailey has served his country with distinction. After the War he returned with undiminished vigour to Geology, and we look forward with pleasant anticipation to the publication in the near future of the results of his researches in the Island of Mull. In the course of military service, he found opportunity to describe the igneous rocks of Drake's Island in Plymouth Sound. Among other contributions to Geology, I may mention Mr. Bailey's work on the petrology of Carboniferous and Old Red Sandstone rocks, and that with Prof. P. F. Kendall on the glaciation of East Lothian. In handing the Bigsby Medal to you for transmission to the Medallist, I would ask you to express to him our regret that he was unable to be with us to-day.

Mr. Lamplugh, in reply, said:—

Mr. President,—

I will ask your permission to read the following communication received from the Medallist:—'Please convey my thanks to the President and Council for the honour that they have done me in recognizing my efforts towards the furtherance of Highland Geology. We in Scotland are fortunate, in that our difficulties are our delight; and, as we face them, we always remember a little band of pioneers whose devotion in the past has opened up the way for fresh advances.'

Award from the Wollaston Donation Fund.

The President then handed the Balance of the Proceeds of the Wollaston Donation Fund, awarded to Herbert Harold Read, M.Sc., to Dr. J. S. Flett, F.R.S., for transmission to the recipient, addressing him as follows:—

Dr. Flett,—

Almost immediately after joining the staff of the Geological Survey, Mr. Read volunteered for military service. Invalided out of the army in 1917, he began work in the complicated region of Lower Banffshire and Northern Aberdeenshire, and made the fullest use of the opportunities which that region offered for research into the succession of the Highland schists. An important piece of petrographical work was the recognition in

Strathbogie of two identical igneous sequences, separated by an epoch of intense earth-movement. The outstanding feature of Mr. Read's petrographical work, and one that will undoubtedly lead to still more important developments, is the evidence which he has been able to produce from the igneous rocks of Banff and Aberdeen of the great part played by assimilation-processes in petrogenesis.

May I ask you, in transmitting this award to Mr. Read, to assure him of our good wishes for further success in the future?

Award from the Murchison Geological Fund.

In presenting the Balance of the Proceeds of the Murchison Geological Fund to Mr. Thomas Henry Withers, F.G.S., the President addressed him in the following words:—

Mr. Withers,—

The curious group of highly specialized Crustaceans known as Cirripedia is of particular interest to British naturalists as having formed the subject of two monographs by Charles Darwin, on the recent and fossil forms respectively. Darwin worked steadily on his 'beloved barnacles' for eight years: in his autobiography he wrote: 'I do not doubt that Sir E. Bulwer-Lytton had me in mind when he introduced in one of his novels a Professor Long who had written two huge volumes on limpets.' Since Darwin's day but little work had been done on the fossil representatives of the group, and it had become clear that a revision and extension of our knowledge was needed. That work you have been carrying out since 1910, in a manner that has evoked the admiration of your fellow-workers for its care and accuracy in description and its insight into morphological conclusions. That you have enriched systematic lists with many new species is of less importance than the light which you have thrown on the relationships of the various genera, both living and extinct. In awarding you the Proceeds of the Murchison Geological Fund, the Council recognizes, not only the value of the work, but the enthusiasm that has led you to devote your leisure to its preparation and, in many cases, your means to its worthy illustration.

Awards from the Lyell Geological Fund.

The President then handed a moiety of the Balance of the Proceeds of the Lyell Geological Fund, awarded to Prof. William Noel Benson, D.Sc., to Dr. H. H. Thomas for transmission to the recipient, addressing him as follows :—

Dr. Thomas,—

Like many of Prof. Sir T. W. Edgeworth David's students, Dr. Benson directed his earliest research-work to the study of the petrology of igneous rocks, and it was with the intention of dealing with this phase of the subject only that he began, in 1909, an investigation of the Great Serpentine Belt of New South Wales. Finding it impossible to obtain a complete understanding of the igneous rocks without studying also the associated sedimentary strata, he eventually undertook the examination of all the formations over this large area, some hundred miles in extent, and elucidated the sequence of geological events most successfully. This involved long periods of work in the field, followed by detailed petrological and chemical researches at Cambridge, and the comparison of Australian material with specimens in the collections of many Continental universities. Dr. Benson has given us the results of his work in a series of masterly papers, the first of which was published in 1913; and in these he added greatly to our knowledge, not only of the geology of the area investigated, but of the origin of serpentine, of the characters of the spilites and keratophyres, and of the process of albitization involved in their formation.

That his work has been appreciated in the Dominions has been shown from time to time; latterly by his election to the Presidency of Section C of the Australasian Association for the Advancement of Science at its meeting at Melbourne, and by his appointment as Professor of Geology & Mineralogy at the University of Otago. The award to Dr. Benson of a moiety of the Balance of the Lyell Fund is an indication that we also are not unappreciative of his merit. Will you kindly tell him that our confident hope is that he will continue in New Zealand the good work which he began in Australia?

The President then presented the other moiety of the Balance of the Proceeds of the Lyell Geological Fund to Prof. William Thomas Gordon, D.Sc., addressing him as follows:—

Dr. Gordon,—

The encouraging friendliness of the Society to workers who have made the botanical side of Palæontology their chief concern may fairly be said to have reached its maximum development at this particular moment of geological history. It is a great pleasure to me to have the honour of presenting a moiety of the Balance of the Lyell Fund to a fellow-palæobotanist who has added very materially to our knowledge of the morphology of some of the more interesting genera of Lower Carboniferous plants, and, more recently, has thrown light upon certain Cambrian organisms dredged from the floor of the Antarctic Ocean. You have not been content to investigate material provided by others; you have shown yourself to be equally at home as a collector in the field, and as a lapidary and a microscopist in the laboratory. You have attacked very difficult problems, particularly the elucidation of the structure of some of the oldest Ferns, and in this field you have been conspicuously successful.

The work which you have done is highly appreciated by your colleagues, both at home and abroad. I sincerely hope that you will long continue to devote your attention and those Scottish qualities, which some of us regard with envy, to the problems of Palæozoic Botany still awaiting solution in the rich herbaria on the shores of the Firth of Forth.

THE ANNIVERSARY ADDRESS OF THE PRESIDENT,

ALBERT CHARLES SEWARD, Sc.D., F.R.S.

DURING the past year the Society has lost three Foreign Members, Prof. Capellini, Prof. Issel, and Dr. Reusch. The tragic circumstances of the death of Dr. Reusch add poignancy to our sense of the grievous loss which Geology has suffered. For the obituary notice of Prof. Capellini I am indebted to our Foreign Secretary, Sir Archibald Geikie, for that of Dr. Reusch to Dr. A. Harker, and for the notice of Prof. Issel to Dr. A. Smith Woodward. We have also lost one Foreign Correspondent, Prof. Theodor Liebisch. I have further to record the death of twenty-nine Fellows. I take this opportunity of thanking for their kind assistance those Fellows whose initials are appended to the obituary notices.

By the death of GIOVANNI CAPELLINI on May 28th, 1922, Italy was deprived of her most prominent geologist. Born at Spezia in 1833, he was early led to interest himself in the rocks of that picturesque district. After studying natural history at the University of Pisa, he was eventually appointed to the Professorship of Geology at Bologna, which he held with distinction to the end of his life. He devoted himself to the investigation of the geology and palæontology of the Appennine chain, and to the formation of a Museum in which the principles of geology were illustrated by specimens gathered from a wide field of observation, not only in Italy but in foreign countries. Besides availing himself of the geological riches of the eastern slopes of the Appennine chain, so conveniently reached from Bologna as a centre, he was ultimately led to pass his summer retreat at Spezia, whence he studied the western side of the great mountain-mass. He specially worked out the stratigraphy and palæontology of the Infra-Lias, embodying his researches in an important memoir. He also brought to light the volcanic rocks of the province of Pisa. Capellini was perhaps more widely known personally among the geologists of the world than any other cultivator of the science. Not only did he travel widely, but for many years he was one of the most constant supporters of the International Geological Congress. He had taken an active part in the formative meeting of that body held at Bologna in 1881, and he

continued to attend the subsequent gatherings in European capitals until the war put a stop to them. He spoke French fluently, but with a strong Italian accent. His courtesy and kindliness made him welcome everywhere. His services to science were recognized by various Governments and Academies in the bestowal of decorations. These he used to wear at the Congress meetings, where he was always a conspicuous figure from the number of ribbons and crosses that hung on his breast. [A. G.]

Hans Henrik Reusch was born at Bergen in 1852. His devotion to Geology dates from his student days. After graduating in 1875 he became Assistant to the Norwegian Geological Survey, but retained his connexion with the University until 1888. Upon the death of Prof. Kjerulf in that year, Reusch was appointed Chief of the Survey, and entered upon the career which was his life-work. His personal contributions to the geology of his country were numerous and important. At an early date he detected fossil remains in some of the schistose rocks of the Bergen district. This discovery, announced in 1880, still has its interest in connexion with the possible Caledonian age of the regional metamorphism in extensive tracts of Norway. In 1888 appeared a valuable monograph on the Bommel and Karm Islands. In the prosecution of his researches Reusch travelled widely over the length and breadth of Norway. The staff of the Norwegian Geological Survey has at no time been large, and at first consisted of the Chief and one permanent Assistant: consequently the maps, memoirs, and year-books issued in the name of the Survey represent in many instances the single-handed labours of the Chief.

In addition to his own contributions to Geology, both pure and applied, Reusch took part in geological activities of every kind, and had a keen interest in the promotion of scientific knowledge. He was instrumental in starting in 1877 the popular journal 'Naturen,' which has done much towards spreading an interest in science in the Scandinavian countries. He was also one of the founders, in 1905, of the Norwegian Geological Society. His modest and amiable disposition made many friends, and his eminent services to Geology brought him some well-merited honours. He was elected a Foreign Correspondent of our Society in 1889 and a Foreign Member in 1897, and in 1895 he was the recipient of the Lyell Medal. In 1907, as a delegate to our

Centenary Celebration, he received the honorary degree of Doctor in Sciences from the University of Oxford.

In 1921 Reusch resigned the Directorship of the Geological Survey to make place for a younger man; but he was not to enjoy long the relaxation thus gained. The story of his end, as conveyed by his lifelong friend, Prof. W. C. Brögger, is a tragic and pathetic one. In October of last year he took possession of a cottage which he had purchased at Hvalstad, some 12 miles from Christiania. On the following day he left his new home to attend a meeting of the Council of the Norwegian Geological Society; but, on attempting to enter an electric train while in motion, he fell, and was crushed beneath the wheels. He leaves a name which will live in Norwegian geology, and will recall pleasant memories to all who knew him. [A. H.]

Arturo Issel, who was elected a Foreign Correspondent of our Society in 1900 and a Foreign Member in 1907, was born at Genoa on April 11th, 1842, and graduated with honours in Natural Science at Pisa in 1863. He was an all-round naturalist, and during his extensive travels in the Mediterranean and Red-Sea regions he devoted especial attention to the Mollusca, both living and fossil. In 1869 he published an important volume on the Malacology of the Red Sea. In 1866, however, he had been appointed Professor of Geology & Mineralogy in the University of Genoa, and he held the Professorship of Geology alone until 1917. He thus began most active and varied research in geology, and continued his valuable work without ceasing until his well-earned retirement. He studied the geology of his native Liguria from every point of view, and in 1892 he published two exhaustive volumes on the Geology and Prehistory of the country. He was especially interested in the exploration of the caves on the coast. For some years he was President of the Royal Geological Committee and of the Geological Society of Italy, and he was very active in fostering scientific research in Genoa. His personal charm and enthusiasm made him an ideal teacher and colleague, and his scientific worth was acknowledged by the many honours conferred on him by the Institute of France, the Geographical Society of Italy, and other Societies, including our own. Prof. Issel died at Genoa on November 27th, 1922. [A. S. W.]

Theodor Liebisch was elected a Foreign Correpondent of our Society in 1899. He was born at Breslau, where he graduated in 1874; he became Professor of Mineralogy successively at Breslau, Greifswald, Königsberg, and Göttingen. Since 1908 he had been Professor of Mineralogy & Crystallography and Director of the Mineralogical & Petrographical Institute & Museum in the University of Berlin. From 1885 to 1921 he was one of the joint Editors of the 'Neues Jahrbuch für Mineralogie, Geologie und Paläontologie.' His earliest paper (a dissertation in 1874) was petrographical, dealing with the erratics of northern igneous rocks found in Silesia; but all his later papers relate to the geometrical, optical, and physical properties of crystals, and to instruments for the determination of these. Apart from his teaching, he was best known through his profound treatises on geometrical and physical crystallography. He died on February 9th, 1922.

[L. J. S.]

William Carruthers was born at Moffat (Dumfries-shire) on May 29th, 1830; he died on June 2nd, 1922. His intention was to become a Minister in the Presbyterian Church; but, although circumstances led him to follow a scientific career, he never lost his youthful theological enthusiasm. Primarily a botanist, Keeper of the Botanical Department of the British Museum from 1871 to 1895, and Botanist to the Royal Agricultural Society from 1871 to 1909, he was for more than fifty years a Fellow of the Geological Society. Fifty-four years ago a grant from the Wollaston Fund was awarded to him, and from 1884 to 1886 he held the office of Vice-President. In 1858 he published a paper on Dumfries-shire Graptolites, and this was followed a few years later by two other geological contributions. The first of a long series of memoirs on the plants of former ages was published in 1865. Carruthers was one of a small and distinguished band of naturalists who were largely responsible for the application of scientific methods to the study of extinct plants. Within a short time, especially in the decade 1867–1877, before he became deeply immersed in official duties, he made valuable contributions to our knowledge of different floras and many genera of fossil plants. He described an early Tertiary Osmundaceous fern from Herne Bay, a tree-fern from the Upper Greensand of Shaftesbury, several new Cycads and Conifers from Mesozoic rocks, Permo-Carboniferous plants from Brazil and Queensland, Lepidodendra, Calamites, and other genera

from the Coal Measures. He was the first to recognize the true morphological nature of the tissue of the problematical Silurian and Devonian genus *Nematophycus*, a discovery which involved him in a lengthy, though by no means dull, controversy with the late Sir William Dawson. He ranged over the whole domain of the plant-kingdom, and applied his extensive knowledge of existing forms to the interpretation of palæobotanical records successively from Silurian to Tertiary strata. The services of Carruthers to the Botany of the past cannot be adequately measured by reference to his published work. After he ceased to publish original papers on palæobotanical subjects, he continued to exert a considerable influence upon younger workers. As I can gratefully testify, by his uniform kindness and generosity, by giving to the less experienced the benefit of his fuller knowledge, and by placing unreservedly at their disposal material accumulated for his own researches, he did what he could to imbue students with something of his own wisdom and enthusiasm. It is difficult to make a selection, for special mention, from the variety of subjects on which Carruthers wrote; but I venture to think that his papers on the Mesozoic Cycadophyta played the most conspicuous part in placing his name among the leaders of palæobotanical investigations.

A full account of the botanical work of Dr. Carruthers will be found in a very interesting article 'In Memory of William Carruthers', by Mr. James Britten, in the Journal of Botany for September, 1922.

Thomas Vincent Holmes was born at Kirklinton Hall (Cumberland) on May 18th, 1843; he died at Greenwich on January 24th, 1923. He was educated at a private school at Mitcham (Surrey) and at King's College, London. While at College he was a keen Volunteer, reaching the rank of sergeant in the College company of the Westminster Rifles. From his youth he was of a studious nature, and a great reader throughout his life. He married his cousin, Mary Winder, in 1868: her life was a short one, and in 1873 he married his second wife, with whom he lived for nearly fifty years, until her death on Christmas Day, 1922, about four weeks before his own. In April 1868 he joined the Geological Survey, on which he served until July 1879. His work was chiefly in Cumberland, but he was also concerned with mapping the Yorkshire Coalfield. Long after leaving the Survey

he took a large part in the compilation of the Memoir on the Thicknesses of Strata, published in 1916. This was presumably his latest work. He was elected a Fellow of our Society in 1876; he became a Member of the Geologists' Association in 1879, and was its President in 1889–1891. He joined the British Association in 1882, and in the same year the Essex Field-Club (of which he was President in 1886–1888). A frequent attendant at the meetings and excursions of the Geologists' Association and of the Essex Field-Club for many years, he helped greatly in their work, and his genial companionship was much valued. The later years of his life were spent in the old house which belonged to his parents, 28 Crooms Hill, facing Greenwich Park, and there he died, leaving three sons and three daughters.

His chief geological contributions, other than the work done for the Geological Survey (which included a Memoir on the country around Carlisle, 1899), are included in the following papers:—three published by our Society; the first in 1881, on the Carlisle basin, and two, in 1892–1894, dealing with the relation of the River-Gravels of the Lower Thames to the Boulder Clay. His most important contributions to the Geologists' Association were on Cumberland, in 1882 & 1887, and his Presidential Address, on the Geological Record, in 1890–1891. He read many papers to the Essex Field-Club, including two Presidential Addresses, the second of which was on the subterranean geology of the South-East of England. He dealt also with the following subjects:—Subsidences at Lexden, 1887; Drift Maps, 1888; the Ancient Physiography of Essex, 1896; the new Reservoir at Walthamstow (two papers), 1901; Subsidence at Mucking, 1907. Besides these, there are many other shorter papers in the 'Essex Naturalist' and a multitude of notes, and papers on subjects not wholly geological, notably the Report on Deneholes, and two papers on Tree-Trunk Water-Pipes, 1903. His active scientific work ended in 1914. [W. W.]

Howard Fox, of Falmouth, was a member of the well-known and much-respected Fox family. His first cousin, Caroline Fox, daughter of Robert Were Fox, F.R.S., in her book 'Memories of Old Friends', referring to a luncheon party at Falmouth on April 7th, 1836, gives the following picture of De la Beche, whose work in Cornwall was worthily continued by Howard Fox:—

'He is a very entertaining person, his manners rather French, his conversation

spirited and full of illustrative anecdote. He looks about forty, a handsome but careworn face, brown eyes and hair, and gold spectacles. He exhibited and explained the geological maps of Devon and Cornwall which he is now perfecting for the Ordnance (Survey).'

Howard Fox was born at Falmouth in 1836, and worthily carried on the traditions of his family, not only in the matter of social gifts and personal kindliness, but also in scientific research and the love of Nature. For seventy years he was connected with the shipping firm of G. C. Fox & Co., occupying various consular posts, including that of American Consul, which had been held almost continuously from the time of George Washington by members of the Fox family, until the consular agency at Falmouth was merged in that at Plymouth. He devoted his leisure mainly to fishing, gardening, botany, and geology. His wonderful garden at Rosehill was a delight to his friends, as also to many strangers who had heard of its fame and were warmly welcomed by him. But it is with his geological work that we are especially concerned. His keen eye, coupled with a vigorous frame and a love of outdoor life on land and sea, enabled him to make many notable discoveries. He traced the radiolarian cherts (Codden Hill Beds) from Cornwall through Devon to West Somerset and, in conjunction with G. J. Hinde, contributed an important paper to our Journal. It is due to him that the radiolarian cherts and pillow-lavas of Mullion Island were discovered, and proved to be present in other areas of West Cornwall where Ordovician rocks occur. He explored every nook and corner of the Lizard coast. He proved that the Man o' War rocks are formed of a corrugated igneous gneiss, totally different from any rocks occurring *in situ* on the mainland. He was also instrumental in throwing additional light on the vexed questions connected with the mutual relations of the three main rock-groups of which the peninsula is composed—the 'granulate' series, the serpentine, and the hornblende-schist. Howard Fox was essentially a field-geologist. All who were brought into personal contact with him were captivated by his geniality and stimulated by his enthusiasm. The records of his work are to be found in the Transactions of the Royal Geological Society of Cornwall, of which he was President during the years 1892–94, the 'Geological Magazine,' our own Journal, and other scientific periodicals. He died at Falmouth on November 15th, 1922, at the ripe age of eighty-six, and was laid to rest in the Friends' Burial-ground at Budock. [J. J. H. T.]

Ernest Westlake was born on November 16th, 1856, elected a Fellow of our Society in 1879, and died, as the result of a motor accident, in 1922. He was a devoted student and lover of Nature, and although he published little, he contributed largely to Science in other ways. The fossil remains of Man were his especial study, and he leaves behind three unrivalled collections of stone-implements. One of these represents the Chellean industry as preserved in gravels near Godshill (Hampshire). The others were brought together in an attempt to solve the problem of Tertiary Man. This led in the first place to a journey to Tasmania, where he visited many of the ancient camps and obtained several thousand specimens of the handiwork of the extinct Tasmanian race. Equipped with the knowledge thus obtained, he went next to Aurillac and found a residence close to Puy Boudien, where he remained actively digging in the Upper Miocene gravels for nearly a year. As a result, he amassed a collection of some 4000 chipped flints of undoubted Miocene age, which are now in course of examination by experts on the manufacture of flint-implements. The collection is accompanied by a long paper on the geology of Puy Boudien and its neighbourhood.

In Ernest Westlake a remarkably original mind was united with a delightful simplicity of character. As an instance of his public spirit, it may be mentioned that, when the beautiful wood of Sandy Bales on the border of the New Forest was threatened with destruction by the timber-merchant, he rescued it, though not a rich man, at his personal expense, for the perpetual enjoyment of all lovers of Nature. It is in the centre of this secluded spot that he finds his last resting-place. [W. J. S.]

Sir William Phipson Beale, Baronet, K.C. (1839–1922) had a strong personality, and was well known in legal and political circles. At the Bar he specialized in patent cases, and he sat in Parliament as Liberal Member for South Ayrshire from 1906 to 1918. He was much interested in several branches of science, joining the Geological Society in 1865 and the Chemical Society in 1867; and he was President of the Mineralogical Society during 1918–21. His mathematical treatise on crystallography, published in 1915, was modestly styled 'An Amateur's Introduction to Crystallography', the designation 'amateur' being intended to apply both to the author and to the reader. He was created a Baronet in 1912, and died on April 13th, 1922, at the age of eighty-two. [L. J. S.]

George Simmonds Boulger (1853–1922) was a keen naturalist from his earliest childhood; he was appointed Professor of Natural History at the Royal Agricultural College, Cirencester, in 1876, and occupied the chair for thirty years. As a lecturer on many scientific subjects, as author of a book on Elementary Geology, of several botanical volumes, and as an active contributor to natural-history periodicals he rendered valuable service to biological science in the widest sense, and played a prominent part in spreading the gospel of Science among the people. He was elected into our Society in 1875.

A full account of Boulger's botanical work will be found in an article by Mr. James Britten, in the Journal of Botany for August, 1922.

Alfred Edward Carey was born at Wargrave (Berkshire) on February 25th, 1852; he died at Reigate on December 30th, 1922. He began his career as a Civil Engineer in the Way & Works department of the London, Brighton, & South Coast Railway Company, and was afterwards appointed Resident Engineer to the Newhaven Harbour Company for the construction of the harbour, which began in 1878. Subsequent to his experience in marine work, Mr. Carey became a Consulting Engineer, first at Brighton and later at Westminster. For many years he was a keen collector of flint-implements. His principal technical work was published in 1918; it was a study of foreshore problems, entitled 'Tidal Lands', written in collaboration with Prof. F. W. Oliver. He had been a Fellow of this Society since 1887.

John Casper Branner, President Emeritus of Stanford University, California, died in his seventy-second year on March 1st, 1922. After serving as Director of the Imperial Survey Commission in Brazil, where he worked both as botanist and geologist, he was appointed, in 1885, Professor of Geology in the University of Indiana; in 1892 he was elected to the geological chair at Stanford University, and subsequently became President. Branner made many noteworthy contributions to Geology, as the result of his survey-work in Brazil and in different parts of the United States. He became a Fellow of our Society in 1898.

Alfred Harper Curtis was born on July 12th, 1863: by his death, on January 10th, 1923, the Imperial Mineral Resources

Bureau loses an able and highly-esteemed member of its staff. After spending three years with an engineering firm at Swansea, he became a student at Owen's College, Manchester, and later at the Royal School of Mines. On leaving London he travelled widely in many parts of the Empire and in foreign countries. His paper on 'Gold-Quartz Reduction' gained for him the Telford Premium of the Institution of Civil Engineers. While in New Zealand, during the period 1896–1902, he was a member of the Council and one of the Honorary Secretaries of the New Zealand Institute of Mining Engineers. During the war Mr. Curtis gave much time to the preparation of reports dealing with the mineral resources of the Empire and foreign countries: he joined the staff of the Imperial Mineral Resources Bureau, and took a prominent part in the compilation of the statistical and descriptive reports issued by that Bureau. He will be remembered by his colleagues as an untiring and conscientious worker, and his death leaves a gap which it will be difficult to fill. He had been a Fellow of our Society since 1891. [F. H. H.]

Leslie Alfred Edward Swinney died from blackwater fever on September 13th, 1921, in the jungle 30 miles from Alor Star, Kedah (Malay States). After obtaining a first-class diploma at the Imperial College of Science & Technology, he worked as a mining engineer in Canada, Norway, West Africa, the Transvaal, Chile, Sumatra, and India. Enlisting as a private on the outbreak of the War, he reached the rank of major in the Royal Engineers. One who knew him writes: 'a miner of vast experience and exceptional ability; he was a true and faithful friend of sterling worth'. Mr. Swinney was elected a Fellow of this Society in 1908.

William Henry Booth, whose death occurred on November 12th, 1921, had been elected a Fellow of our Society in 1909. He was an engineer by profession, and for a short time edited 'The Mechanical World.' He travelled extensively abroad in his professional capacity, and was led to take a keen interest in geological problems. In later years he was chiefly engaged in water-supply work in this country. [J. P.]

P. Charteris A. Stewart, whose death by drowning while bathing at Balandra Bay (Trinidad) was reported in January,

1923, was well known as a geologist and petroleum technologist. At the time of his death he had been connected for nearly twenty years with Viscount Cowdray's firm (Messrs. S. Pearson & Son), and had been closely associated with them in their oil enterprises. Before that he was on the staff of the Egyptian Geological Survey. Mr. Stewart's death, at the age of forty-six, has cut short a promising career, and his loss will be keenly felt, not only by his friends but by all connected with the British petroleum-industry. He had been a Fellow of this Society since 1904.

Joseph William Winthrop Spencer was born at Dundas (Ontario) in 1851, and graduated at McGill University in 1874. His best work was in connexion with the Glacial Lakes: he proved the differential elevation of the old shores of Lake Iroquois, to which he gave its appropriate name. He published many papers on that and other ancient lakes; but his most important publication was on the Evolution of the Falls of Niagara (Geological Survey of Canada, 1907), in which he summarized the results of his Pleistocene work, and made a time-table for the recession of the Niagara Falls from the escarpment of Queenston. This was the first approximately accurate estimate of the age of the Falls and of the length of time which had elapsed since the ice had left the Great Lakes region. He traced some river-channels, such as that of the St. Lawrence, by means of soundings on the charts to the edge of the continental shelf, thus proving the former elevation of the American continent. Dr. Spencer was for a few years State Geologist of Georgia, and was one of the earlier Fellows of the Geological Society of America. He became a Fellow of our own Society in 1877. [A. P. C.]

Thomas William Reader was born on March 12th, 1860, and died on January 29th, 1923. As an enthusiastic and skilful photographer, he rendered valuable service to Geological Science. More than a hundred of his photographs are published in the Proceedings of the Geologists' Association, and it was primarily in recognition of his ability in the important ancillary science of photography—an ability which he generously used in helping others—that the Geologists' Association selected him to be the first recipient of the Foulerton Award, in 1920. For several years Mr. Reader was Librarian of the Essex Field-Club, and took a prominent part in arranging the geological collections at the Essex

Museum of Natural History, West Ham. It was by teaching (at Morley College, Toynbee Hall, and other places), by collecting material, and by his photographic work rather than by writing papers, that Mr. Reader contributed unostentatiously to the advancement of Archæological and Geological Science. He had been a Fellow of our Society since 1891.

THE EARLIER RECORDS OF PLANT-LIFE.

The occupant of the Presidential chair has exceptional opportunities of appreciating the extent and varied character of the field which geologists are industriously tilling; he is made conscious of the fact, that to speak intelligently with his fellow-workers in the dialects of their respective branches of the subject, is beyond the reach of the ordinary specialist. Omniscience is to the few; fortunately, to the very few.

I cannot claim to be a geologist: there was a time when, with the confidence of youth, I fancied that the term might not be inapplicable; but, acting on the advice of the late Prof. T. McKenny Hughes, I left the main geological highway, and took to the botanical road with the ultimate object of devoting myself, so far as circumstances would permit, to the study of fossil plants. The road which was followed, though it lead to pleasant places, passed through a country for the greater part remote from that of the geologist. The invitation to be your President was regarded as an assurance that, in the opinion of the representatives of the science to which I had mainly devoted myself as an undergraduate, my small contributions to the botany of the past come within the purview of the Society. Labour is said to be its own reward; but to most of us the reward which gives the greatest pleasure and the strongest stimulus is derived from the kindness and encouragement of colleagues. It was the consciousness that the Society desired to extend to Palæobotany a recognition equal to that previously given to other branches of Geology in the broadest sense, which gave me courage to follow my own inclination, instead of asking myself how far I could expect to perform efficiently the duties pertaining to this exalted position.

A considerable portion of palæobotanical work is concerned with the description of the waifs and strays of floras of different ages

and countries: facts, or what authors are pleased to regard as facts, are accumulated in large quantity, and in these days of scientific activity there is a danger of becoming wholly absorbed in the task of adding to the pile of data, without pausing to consider the value of the material as evidence upon which to base conclusions of general interest. A student of science cannot go far without allowing some play to the imagination. As 'in historical enquiries', we are told, 'imagination must always supply the cement that binds together the broken fragments of tradition', so it is in enquiries into the events of pre-history. I venture to think that one of the many privileges of a President is that he may permit himself a reasonable amount of speculation in endeavouring to present some of the wider aspects of his subject.

My aim this afternoon is to penetrate into the remote past of the history of plant-life, briefly to examine some of the early records, and to follow the course of evolution up to the threshold of the period at which Palæozoic vegetation reached its maximum development. All that I can do is critically to examine the available documents, and to interpret such as are believed to be genuine by means of a few impressionist sketches.

'Geology by itself has not yet revealed, and is not likely ever to reveal, a portion of the first crust of our globe': we may supplement these words of Sir Archibald Geikie with the statement that, search as we may, we shall never discover the truly primitive ancestors of the organic kingdom. On the other hand, the more we learn of the physical-chemical attributes of living protoplasm, the better equipped shall we be to speculate upon the conditions under which life began. Where was the first link in the chain of life forged? Was it on 'the boundless shores of an azoic sea'—words which recall a striking passage in a sermon by Prof. T. G. Bonney to which I listened nearly forty years ago—on the muddy margin 'of a primeval lagoon', in the waters of the first world-ocean, or, as was recently suggested, 'on the mountain-tops of the polar regions'?

Existence in water and on land are two very different aspects of plant-life. A water-plant is surrounded by the raw material of its food, air, and solutions of salts; it can absorb at any part of its surface, and has no concern, either with the provision of an elaborate mechanism for the conduction of water from root to tip of stem,

or with methods of guarding against excessive loss of water by evaporation from its leaves. In a plant rooted in the ground absorption is localized, provision must be made for an ascending water-current and for the regulation of transpiration. The life-history as also the structure of a plant are affected by the nature of the environment. The majority of biologists probably believe that life began in the sea: it is easier for many of us to picture the birth in the sea of living organisms capable of building up their substance from carbon-dioxide gas and mineral salts under the influence of solar energy, than to imagine a similar act of creation on land or in a freshwater lake. Assuming the first scene to have been enacted in the ocean, what were the events which led to the subsequent evolution of the pioneers of a land-vegetation? It would be out of place to discuss the various hypotheses which have been advanced, but I cannot refrain from a brief reference to an ingenious and able attempt recently made by Dr. A. H. Church, of Oxford, to follow the steps of the great migration of the vegetation of the ocean to the surface of the land. He regards as untenable the view that it was from simple freshwater Algæ, which had wandered from their original home in the sea, that the earliest land-plants were derived. Dr. Church sees the birth of free-floating unicellular plants in the waters of a world-ocean. At a later stage, when the uplifting of portions of the earth's crust raised the ocean-floor within range of the sun's rays, the floating plants were able to attach themselves to the solid substratum, and a further step was taken in the elaboration of the plant-body. A Plankton phase of floating life was followed by a Benthic phase, when a sedentary existence favoured the evolution of a relatively complex type of construction. When portions of the crust emerged above the water, the submarine vegetation was faced with fresh problems consequent on the change from water to air. Power to live under the new conditions could only be gained by drastic structural changes: the plants which solved the problem were the advance-guard of the vegetation of the land. The assumption of the existence of an ocean which completely enveloped the earth before the beginning of the geological record presents many difficulties; on the other hand, as Prof. A. S. Eddington recently stated, a world-ocean is not inconceivable to an astronomer. But, although Dr. Church postulated a world completely covered by water, I venture to think that the stages in the evolution of a terrestrial vegetation which he describes do not demand such an

assumption. There is something attractive in the idea of deriving plants of the land from highly organized inhabitants of the ocean-floor; and, in my view at least, there is no insuperable objection to the conception that terrestrial vegetation received additions from upraised portions of the crust at more than one epoch in the history of the earth.

One may hazard the opinion that palæobotanical research has not made it easy to picture the course of evolution through the ages as a single and continuous process. Dynasties rise with apparent suddenness into prominence; after a longer or shorter period of existence, during which comparatively slight changes occur, they are superseded, again with apparent suddenness, by newer and more vigorous races. It would almost seem that 'missing links' never existed. The vegetation of the land that has passed across the world's stage cannot be correctly represented as a tree with many branches. Its development, seen in perspective, appears as a series of separate lines, some stretching into a remote past, others of more recent origin; the impression received is that the starting-points of new lines are not scattered irregularly over the path of geological history, but rather that there is a more or less definite grouping at certain clearly marked periods, nodal points in the history of evolution. I have elsewhere expressed the opinion that the late Palæozoic floras differ considerably from those preserved in Triassic strata: the older lines of evolution came to an end; a new series began. In a word, the history of vegetation, like the history of the rocks, is characterized by cycles; there were revolutions in the organic as in the inorganic world. As the late Dr. J. Barrell said, 'Nature vibrates with rhythms'. There is no absolute break in continuity, but apparently sudden changes in the dominant types. The conception of 'Nature's unchanging harmony' is not inconsistent with variations in the manner of its manifestation. We cannot hope to follow the unfolding of plant-life, unless we keep before us the historical background.

The Pre-Cambrian Era.

For the sake of simplicity, the term Archæan is used in this sketch as equivalent to Pre-Cambrian, without always attempting to draw a distinction between Archæan in the narrower sense, the Lewisian of British geologists, and an upper, Algonkian or Proterozoic series. In order to realize the duration of the Archæan Era as a whole, it is important to bear in mind that the

Upper Archæan strata do not form one continuous series; the occurrence within the system of several marked unconformities denotes pauses in sedimentation, the uplifting of mountain-chains, the removal of millions of cubic feet of rock, and the subsequent submergence of the denuded land to form the foundation for later accumulations of sedimentary material. It has been calculated that the Pre-Cambrian sedimentary rocks of China (and they are but a part of the whole Archæan System in that region) indicate a lapse of time at least equal to that represented by almost the whole of the Palæozoic periods. Another computation assigns to the Upper Archæan series a duration possibly equivalent to that represented by all succeeding geological periods combined. It is only with the rocks which can be identified as sedimentary or terrestrial that we are concerned, not with those which are igneous in origin, or, if originally sedimentary, too highly metamorphosed to be recognized as such. Our task is to discover traces of Archæan life, to visualize the physical conditions, and to form an estimate of the climate. In the earlier geological periods, we are assured, the sun may well have been much hotter than it is to-day; but, whether we adhere in the main to the nebular hypothesis, or adopt the planetesimal views of T. C. Chamberlin and H. G. Moulton, there would seem to be no reason to suppose that on the Archæan land the temperature was such as cannot be matched in certain regions of the world to-day. Geological researches do not justify the statement that there has been a gradual decline in the temperature at the surface of the earth in the course of ages. There is overwhelming evidence against the old view that the glacial phase in the Pleistocene Period was the result of the 'natural trend of a moribund earth towards a cold senility'. Recurrent glacial conditions were a normal phenomenon throughout geological time. Tillites of Archæan age, reaching 500 feet in thickness, cover a wide area in Canada, occurring at localities 1000 miles apart from east to west and 750 miles apart from south to north. I am indebted to Prof. A. P. Coleman for a photograph of an ice-scratched boulder, reproduced in the recently published book on 'Elementary Geology' by himself & Mr. W. A. Parks in illustration of the glacial origin of these deposits. Archæan boulder-beds are recorded also from South Africa, and tillites, probably of similar age, occur in the Simla district in India. Cambrian, or possibly Upper Archæan, tillites on a large scale have been discovered in China, and undoubted glacial beds in Norway are

either Ordovician or Silurian in age. Archæan tillites occur in South Australia, containing erratic blocks up to 10 feet in diameter in beds 1500 feet thick. It is but fair to state that the glacial origin of these beds, though accepted by Sir T. W. Edgeworth David, Prof. W. Howchin, and other geologists, is denied by Dr. H. Basedow with a confidence which fails to carry conviction. In some parts of the Archæan world the climate was arctic rather than tropical.

In Montana it is estimated that there are upwards of 30,000 feet of unaltered sedimentary strata between the older Archæan rocks and the Cambrian System. It is a remarkable fact that, while marine Cambrian sedimentary strata have yielded a rich harvest of animal fossils, thousands of feet of practically unaltered Archæan rocks are almost completely barren. The Vindhyan System of India, over 1400 feet thick, made up of sandstones, frequently ripple-marked and sun-cracked, shales, and limestones, occupying much the same position in the geological series as the Torridonian of Scotland, is characterized by an almost complete absence of fossils. The absence of marine life, save a few fossils of doubtful value referred to the Algæ, in the enormous thickness of the Late Archæan series exposed in the Grand Cañon and in other places which have been searched during the last thirty years, although it has been attributed to the obliteration of any fossils that may have been present by the destructive action of heat, cannot be thus explained.

It is noteworthy that records of animal life in Archæan seas are not above suspicion: Dr. C. D. Walcott instituted the generic name *Beltina* for crustacean fragments said to be Algonkian in age; but Dr. R. A. Daly favours a Cambrian horizon for the *Beltina* Beds. Prof. L. Cayeux recorded many Pre-Cambrian foraminifera and other organisms from Britanny, but H. Rauff denied their organic nature. In the British Isles, in China, India, and in many other parts of the world the Pre-Cambrian rocks are equally barren. Evidence is not lacking that much of the Upper Archæan sedimentary material was accumulated on land and not under water, and in an arid climate. Attention has often been called to the remarkable freshness of the felspars in the Torridonian grits of the North-West Highlands, which suggests a rapid disintegration rather than decomposition by chemical action. Dr. B. N. Peach and Dr. J. Horne conclude that the climate was probably cold, and that there were periodic floods of great intensity.

Prof. J. Walther compares Torridonian conditions with those of a modern sub-tropical desert where icy storms alternate with tropical rains. Pebbles from the Torridon grits, and from strata of similar age in Sweden, bear the impress of the action of sand-blasts. The frequent occurrence of red deposits in different Archæan regions is adduced as further evidence of a dry climate.

A land bare of vegetation, mountain-sides exposed to the destructive influences of sharply-contrasted day and night temperatures, avalanches of rock, restlessly drifting sand-dunes, floods following torrential rains spreading the disintegrated rock and wind-blown sand in fans and sheets in the valleys: if the conditions were even approximately such as these, it is hardly surprising that we search in vain for the remains of a land-vegetation. But deserts, although probably of vast extent, were not a universal feature of Archæan continents. The unfossiliferous condition of vast piles of sedimentary strata is significant, and it is in the highest degree improbable that, if there had been a vegetation, some relics of it would not have been preserved.

Geological literature contains many references to indirect evidence of plant-life during the latter part of the Archæan Era, and a few descriptions of supposed plants. In some parts of the world carbonaceous rocks and beds of graphite are developed on a comparatively large scale. In the district of Lake George (New York), alternating layers of graphitic shale or schist form beds from 3 to 13 feet thick, described as 'a fossil coal-bed': on the analogy of the nature of more recent coal-seams, the oldest graphitic beds are considered to afford evidence of the occurrence of contemporary vegetation, possibly, it has been suggested, of 'primitive marine plants'. The presence of graphite is not, however, in itself proof of the existence of vegetation. Dr. C. E. Tilley has recently discussed the origin of graphite in Pre-Cambrian rocks in South Australia and other regions: while he believes that a sedimentary origin of the Australian graphite is most closely in accord with the facts, he also recognizes the possibility of the formation of graphite by the reduction of oxides of carbon by hydrogen. A carbonaceous deposit in Finland, which reaches a thickness of about $6\frac{1}{2}$ feet, and is almost pure carbon, is described as undoubtedly organic in origin; but, if organic, we cannot tell whether it be animal or vegetable. In some fine-grained carbonaceous rocks in Finland of Archæan age, which are believed to be metamorphosed sediments, small bodies like empty sacs, crushed and distorted and outlined in

coaly substance, occur parallel to the planes of bedding. It is suggested by their discoverer that these bodies are imperfectly-preserved plants: as records of plant-life they are valueless.

The occurrence of iron-ore in association with Archæan rocks has been adduced as evidence of the existence of plants. It is well known that certain bacteria and other micro-organisms absorb iron from the water in which they live, and ferric hydroxide is deposited. Much has been written on the relation of bacteria to ferruginous deposits by H. Molisch, D. Ellis, E. C. Harder, and, more recently, E. S. Moore; but it would seem impossible to determine by any direct evidence whether the formation of iron-ore in the past should be ascribed to the action of micro-organisms. Phosphatic nodules from Torridonian rocks in Scotland have revealed, on microscopic examination, an appearance recalling irregular groups of small-celled tissue superficially (at least) similar to that of simple plants, although the resemblance may be purely accidental. Limestones are by no means rare in the Archæan System, and for the greater part they have not yielded any satisfactory records of plant-life. Dr. Walcott in 1915 recorded the discovery in sections of an Upper Archæan limestone in Montana of cells and chains of cells, which he considered to be bacteria of the *Micrococcus* type. Such they may be; but, except in very favourable circumstances, it is extremely difficult to draw the line between crystals, or embryo-crystals, and bacterial cells. It has been demonstrated that unfossiliferous calcareous beds may have been formed by the agency of plants. Deposits of chalky mud are now accumulating west of the Bahamas and in the neighbourhood of the Keys of Florida as the result of the precipitation of carbonate of lime by denitrifying bacteria. The examination of calcareous reefs in the Mediterranean, which unquestionably owe their origin to masses of lime-secreting algæ, has demonstrated that portions of the rock have lost all traces of their plant-origin. While some of the Archæan limestones may have been produced through the agency of plants, the occurrence of calcareous rocks cannot reasonably be regarded as evidence of organic origin.

The abstraction by algæ of carbon-dioxide gas from water causes the precipitation of carbonate of lime; the bicarbonate in solution is thrown down as the insoluble carbonate. The frequent association of minute tubes and other presumably plant-structures with oolitic grains in rocks of different ages has led some authors to infer, from the analogy of a similar association in grains

now being formed, that oolitic structure generally is evidence of the presence of living plants. Some oolitic grains and the circular or oval cake-like masses, known in America as 'water-biscuits,' found in freshwater lakes, owe their origin to algal agency. On the other hand, oolitic grains have been formed artificially by the action of sodium carbonate on calcium sulphate. Moreover, the association of plant-cells with grains or pebbles of carbonate of lime may be secondary; the algæ may have invaded the lime-deposits, and need not necessarily have had any share in their precipitation; their presence may be accidental, not causal. The balance of opinion would seem to be against the assumption that the formation of concentric shells of lime necessarily implies the presence of algæ or other plants. Further reference is made to the association of organic structures and oolitic grains in a later section of this Address. There are, however, many recent algæ which have calcareous coral-like bodies; the walls of the living cells become impregnated with carbonate of lime, and the soft-bodied alga is converted into calcareous branches or larger encrusting coral-like masses based on a framework of plant-tissue. These are the calcareous algæ of recent seas which occur in arctic regions, though mainly in tropical and sub-tropical waters, and in marine strata of many geological periods. The abundance of the genus *Lithothamnion* in the North Polar sea, where the temperature rarely rises above 0° C., is a fact to be reckoned with when use is made of calcareous algæ as a measure of climate. In recent years substantial additions to our knowledge of the structure and distribution of Palæozoic representatives of these reef-forming plants have been made by Prof. E. J. Garwood, ably assisted by Miss E. Goodyear. It is noteworthy that the majority, at least, of the specimens described by authors as calcareous algæ from Archæan rocks are not in the strict sense algæ at all, but are bodies varying in form and size, built up of concentric layers or exhibiting an irregular sponge-like texture. They show no cellular structure like that of calcareous algæ, and the only evidence of any connexion with algæ is that, in a very few of them, groups or chains of cells have been discovered on the removal of the calcareous matrix by the action of an acid. Some limestones in Ontario, well down in the Archæan System, reaching a thickness of 500 to 700 feet, have been described as 'almost an aggregate of fossils'. These supposed fossils, which reveal no cellular structure, consist of calcareous bodies, 1 to 15 cm. in diameter, characterized

by a concentric lamination, and traversed by radial canals: on very slender evidence, they are said to be allied to sponges and referred to a new genus—*Atikokania.* It is impossible to determine their nature; if they are organic, one cannot definitely assert that they are animal or vegetable. Prof. Garwood discovered 'some curious oolitic structures' in Spitsbergen, in rocks that are probably Archæan; but they show no sign of algal origin.

Geological literature contains many references to a type of rock-structure especially characteristic of Cambrian rocks, named by James Hall in 1883 *Cryptozoon*, and first described by J. H. Steele in 1825, as calcareous concretions, from Saratoga County (New York). H. P. Cushing, in an account of the Hoyt Limestone of Upper Cambrian age near Saratoga, says that 'perhaps the most striking fossils of the formation are the big, reef-like masses of the organism of unknown nature, known as *Cryptozoon*'. A smooth surface of rock containing specimens of Hall's type-species shows groups of concentric lines forming complete circles or segments of circles cutting one into the other. The matrix in well-preserved specimens is said by Hall to be traversed by minute canals. Dr. G. R. Wieland, who described examples from Cambrian strata in Pennsylvania, suggested *Cryptophycus* as a more appropriate name, since it definitely implies an algal nature, although of this there would seem to be no satisfactory evidence. On the other hand, Prof. O. Holtedahl, who records the occurrence of *Cryptozoon* in Cambrian strata in Norway, in Lower Palæozoic rocks in Ellesmere Land, North-East Greenland, and Spitsbergen, states that similar structures have been found in Triassic strata. This author advocates the employment of Dr. Ernst Kalkowsky's term Stromatolith. The same type of structure has been discovered in Pre-Cambrian rocks in the Belcher Islands of Hudson Bay, and in other regions of North America.

A. Rothpletz gave a full account of *Cryptozoon*, and recognized several distinct forms: he believed it to be organic, but left the genus suspended between the animal and the plant kingdoms. In view of the general belief of those who have examined actual specimens of *Cryptozoon* and studied them *in situ* that its structure is organic in origin, I hesitate to express a contrary opinion. *Cryptozoon* may be the skeleton of an animal; I do not think that it is a plant. An examination of the published figures and photographs and a perusal of the descriptions lead me to express the opinion

that there are no adequate grounds for regarding such structures as those designated *Cryptozoon* and *Atikokania*, or the comparable forms from Carboniferous rocks described by G. Gürich, as fossil algæ or as the products of algal life. There remains the possibility that a clue to the interpretation of such structures may be found in the class of phenomena represented by the so-called Liesegang figures, to which further reference is made later.

In a contribution entitled 'Pre-Cambrian Algonkian Algal Flora', Dr. C. D. Walcott described several new genera from the Cordilleran region of North America, founded on rock-structure which he believes to have been formed through the agency of algæ closely allied to the Cyanophyceæ. These so-called algæ occur in the Newland Limestone of the Belt Series of Montana, possibly in part at least of Pre-Cambrian age, from the base to the summit of a succession of beds 2000 feet thick. It is impossible in the time at my disposal to give a description of the various calcareous bodies described by Walcott: the characters on which the supposed generic distinctions are based are shown in the published plates. My own first-hand acquaintance with them is limited to an examination of some specimens presented by Dr. Walcott to the British Museum. It is with considerable reluctance that I presume to criticize the conclusions of so distinguished a geologist as Dr. Walcott, but it would be less than honest to refrain from expressing my opinion, however little value it may have. All agree, as Walcott states,

'in not having the structure of the higher Algæ. All appear to have been deposited in successive layers, the inner and older serving as a foundation in which the younger filaments grew in variously arranged forms.'

That their formation was in any way connected with algæ is hypothetical. The only evidence of the association of any of these bodies with algæ is that, in a very few examples, the residue left after treatment with acid revealed the presence of a small number of exceedingly minute cell-like structures. If these be cells, their presence does not prove any organic origin for the associated calcareous masses. My attention was drawn by Mr. W. N. Edwards, of the Geological Department of the British Museum, to the resemblance of some of Walcott's genera to concretions found in the Magnesian Limestone from the Durham coast. Careful examination of these concretions led me to suspect very strongly that if, as is generally believed, they are of inorganic origin, a similar

origin must be assigned to the genera described by Walcott. The striking resemblance between the Archæan and the Permian structures has been recognized independently by Prof. Holtedahl, who published some photographs of Magnesian Limestone concretions indistinguishable in any essential features from illustrations published by Walcott. I fail to see that the American specimens have any claim to be regarded as algæ, and I venture to think that they afford no real evidence of the co-operation of plants in their formation. There can be no doubt that chemical and physical factors are sufficient in themselves to produce various types of structure which are often attributed to the agency of plants: it is not unreasonable to suggest that such specimens as Dr. Walcott has described owe their peculiar features to inorganic, and not to organic, causes. Experiments made some years ago by R. E. Liesegang demonstrated the important bearing of diffusion phenomena upon the general question of rock-structure. He found that if a coagulated colloidal solution, a gel, contains a substance in solution, and a second solvent capable of reacting with the former is allowed to diffuse into it, reaction takes place, but not continuously; with the result that the product is deposited in strata separated by apparently clear intervals. If a solution of sodium carbonate is added to a test-tube partly filled with 1 per cent. agar-gelatine containing calcium chloride, calcium carbonate is deposited in a succession of strata. It is at least worth considering whether there may not be more than a superficial resemblance, between the structures produced experimentally and various Stromatoliths and similar bodies generally regarded as organic, and frequently described as algæ.

My primary object in attempting briefly to summarize the various kinds of evidence which have been brought forward in reference to life on Archæan land and in Archæan seas is to emphasize the importance of submitting such documents as are available to a searching examination. It is tempting to endow our own remote ancestors with qualities that we would wish them to have possessed: similarly, a student of evolution in the wider sense may easily allow to fancy more scope than the facts warrant. We know nothing of Archæan land-vegetation. Negative evidence lends support to the suspicion that the continents were bare of plants. The oceans may have been inhabited by hosts of unicellular algæ, and higher forms may have lived on the shelving sea-margins; but of the actual nature of these plants we have no certain knowledge.

If the vegetation of the land arose like Aphrodite from the sea, it is conceivable that, on the first emergence of the foundations of the continents, the plants transferred from water to land had not reached a stage of evolution consistent with adaptation to the new environment. Moreover, as we have seen, it is probable that in some Archæan regions the conditions were not favourable to plant-development. The customary assumption is that life in the Archæan Era was represented by simple forms ill adapted for preservation. The lower branches of genealogical trees are traced back in imagination to a period of which we have no records fit to serve as foundations: the geologist and the palæobotanist usurp the functions of the poet:

> 'And as imagination bodies forth
> The forms of things unknown, the poet's pen
> Turns them to shapes, and gives to airy nothing
> A local habitation and a name.'

The Cambrian, Ordovician, and Silurian Periods.

The outstanding feature of the Cambrian Period is the abundance of marine sediments, formed both in shallow and in comparatively deep water. The extraordinary wealth of the Cambrian fauna, in contrast to the barrenness of the underlying Archæan strata, is illustrated with especial vividness by the remarkable collection of marine fossils described by Dr. C. D. Walcott from Middle Cambrian rocks in Montana and British Columbia more than 6000 feet below the upper limit of the Cambrian System. The animals of the Cambrian seas have been described as 'most intensely modern', and as 'belonging to the same order of nature as that which prevails to-day'. The meagreness of the botanical records precludes any general statement as to the nature of the marine vegetation. In consideration of the absence of any well-defined distinction between the plants recorded from the several Lower Palæozoic systems, and in order that time may be allowed for the inclusion in this very incomplete sketch of some account of the land-vegetation of the Devonian Period, the Cambrian, Ordovician, and Silurian Periods will be reviewed together. The Ordovician sea trangressed over part of the Cambrian land, and, in the clearer waters, beds of limestone, extending as far north as Arctic Alaska, were built up, in part at least, of the calcareous skeletons of animals and plants. But the rocks give no clue to the nature of the pioneers of a land-flora.

The Silurian Period was one of quiet sedimentation in seas teeming with animal life. With a few exceptions Algæ are practically the only plants preserved, but in some localities fragments have been found which may well belong to some of the first representatives of the vegetation of the land.

During the vast cycles of time represented by the Lower Palæozoic systems, to borrow the words of Sir Archibald Geikie, 'generations of sea-creatures came and went in long procession, leaving their relics amidst the ooze of the bottom'. At last, it would seem that we have vestiges of plants which grew above the tides. One is tempted to regard these imperfectly-preserved fragments with the same kind of feeling as that which is evoked by the first flush of light at the end of a long, dark night. But, before passing on to consider the oldest records of a terrestrial vegetation, I propose briefly to consider a few of the genera of Pre-Devonian fossils usually included in the plant-kingdom.

The frequent association of microscopical tubules with oolitic structure in rocks ranging in age from the Cambrian to the Cretaceous Period is a well-established fact. In his Presidential Address to the Geological Section of the British Association in 1913, Prof. E. J. Garwood gave an admirable summary of the available data. The unseptate tubes have been compared with the sheaths surrounding some recent species of the widely-spread blue-green algæ, but August Rothpletz preferred to regard them as cells of a somewhat higher alga allied to the Codiaceæ. We are still unable to say what *Girvanella* is; it may be an alga: it is conceivably similar in nature to the sheaths surrounding existing thread-like bacteria. Whether it deserves all the credit that it has received as a rock-builder is doubtful: its association with oolitic grains may be secondary, not primary. The genus is recorded from Cambrian rocks of China, Australia, Sardinia, and America; from the Ordovician of the Old and New World, the Silurian of Europe and Australia; it occurs in abundance in Carboniferous limestones as also in Jurassic rocks, and has recently been discovered in the Albian Series of Angola. Whatever its true nature, *Girvanella* represents a persistent type.

The genus *Epiphyton*, originally described by J. G. Bornemann from Cambrian rocks in Sardinia, has been discovered in Siberia and, more recently, by Dr. W. T. Gordon in a boulder dredged from the

floor of the Weddell Sea in lat. 62° 10′ S. and believed to be of Cambrian age. The same generic type was discovered by Sir T. W. Edgeworth David and R. Priestley associated with *Archæocyathus* on the Beardmore Glacier moraines. *Epiphyton* is, in all probability, an alga comparable in its unseptate branched tubules to the genus *Sphærocodium*, which ranges from Silurian to Triassic times; but its precise position cannot be determined. In *Solenopora*, first described from Ordovician beds in Esthonia, we have the most satisfactory representative among the older algæ of a true calcareous type. Although no undoubted reproductive cells have been found, the structure of the plant-body, as Dr. A. Brown first demonstrated, agrees closely with that of the recent genus *Lithothamnion*. Detailed descriptions have been published by Prof. Garwood and other authors: I will confine myself to a brief reference to its range in time and its possible relationship to more modern forms. As one of the oldest fossil plants exhibiting internal cellular structure, in contrast to *Cryptozoon* and the supposed algæ described by Dr. Walcott from Upper Archæan rocks in which there is no direct evidence of any organic construction, *Solenopora* is of especial interest. The genus *Lithothamnion*, a member of the Red Calcareous Algæ, with which *Solenopora* is believed to be closely allied, flourishes both in the tropics and in the Polar regions. It is noteworthy that *Solenopora* was widespread in Lower Palæozoic seas, and lived also in the Jurassic Period; while *Lithothamnion* is met with in the more recent Cretaceous and Tertiary strata. We have here one of many examples furnished by the palæobotanical record of the persistence of a certain type of organization through a long succession of geological ages. Persistence of type, and from time to time the apparently sudden influx of new types, rather than a steady progressive development, are among the outstanding features of the history of plant-evolution.

The genus *Nematophycus*, though perhaps better known as a Devonian plant, occurs also in Silurian rocks; *N. hicksi* Dawson was discovered in the Denbighshire Grits, and *N. storriei* Barber in the Wenlock Limestone. Originally named by Dawson *Prototaxites*, the Canadian Devonian species was described by W. Carruthers as a 'colossal seaweed' under the name *Nematophycus*, for which Dawson substituted *Nematophyton*. The type-species *N. logani* Dawson, from the Devonian of Gaspé, is represented by long pieces of stem between 2 and 3 feet in diameter; but, as a rule, the specimens are much smaller.

Loosely arranged and usually unseptate tubes, following a slightly tortuous vertical course, associated with smaller and branched tubular elements, make up the tissues of the stem: no certain information is available as to the nature of the reproductive organs. Silurian and Devonian species agree in essentials. *Nematophycus* is generally regarded as an alga; anatomically it bears a close resemblance to recent members of the Siphoneæ, while in some respects it recalls the larger brown seaweeds. The association with the problematical genus *Pachytheca* both in Canada and in Europe, in Silurian as in Devonian rocks, may be significant. With the confidence which his treatment of controversial subjects usually exhibits, Dr. A. H. Church declines to accept *Nematophycus* as an alga, and assigns it to the Fungi. The point that he makes is interesting: a plant such as an alga, which by the aid of chlorophyll and sunlight manufactures its own food, is provided with a superficial tissue of short cells, or of cells elongated at right-angles to the source of light. No such tissue had been found in *Nematophycus* when Dr. Church published his view. In 1921 Dr. R. Kidston and Prof. W. H. Lang, in the fourth of their epoch-making memoirs on the Devonian plants of Rhynie, described a new species, *Nematophycus taiti*, founded on a very small petrified fragment: a second fragment was described, which, in addition to some vertical tubes, showed a patch of peripheral tissue consisting of tubular elements elongated at right-angles to the surface, a feature demanded by Dr. Church if the genus is to be included in the algæ. Through the kindness of my friend Dr. Kidston, I was able to examine the Rhynie material; and, while it would be presumptuous on my part, after a short inspection of the sections, to question the accuracy of the identification given by the authors of the new species, I cannot refrain from wondering whether the fragments do not agree more closely with the type of structure represented by the genus *Pachytheca*, a genus which indeed may be incorrectly separated from *Nematophycus*. Until additional and larger specimens are discovered, it is hardly possible, either whole-heartedly to accept the conclusions of Kidston & Lang, or definitely to doubt their accuracy. If the Rhynie plant is *Nematophycus*, its discovery supports the old view of Dawson that it grew on land: it occurs in association with the flora of a Devonian marsh. After discussing this point, Kidston & Lang conclude that 'whatever its systematic affinities may prove to be', *Nematophycus* may have been 'a marsh- or land-plant of Silurian and Devonian times'. One is tempted to

ask, may it, perhaps, have originally lived in the sea, surviving the ordeal of translation to a land-habitat without any substantial modification of its anatomical features?

It would lead us too deeply into botanical technicalities to include in a general summary an adequate review of the older fossil records of that family of Algæ known as the Siphoneæ Verticillatæ, green seaweeds which exist in the warmer seas to-day, and are recorded as fossils from Silurian strata upwards. The family, with especial reference to the extinct types, has recently received a comprehensive and able treatment at the hands of Dr. Julius Pia, of Vienna. This author speaks of the Siphoneæ Verticillatæ as a very homogeneous and natural assemblage of Algæ, producing in the course of their long history successive series of new forms, persistent in the retention of family characters, but rapidly changing in the manifold expression of these characters. Palæobotanical research brings to light many examples of fluctuations within the range of a genus or a family; but it fails, I venture to think, to demonstrate lateral connexions between families, classes, and groups. Genealogical trees of the comprehensive type have had their day: single lines of development are clearly discerned, stretching, it may be, to almost infinitely remote ages. Our failure to discover, either the meeting-places of these lines, or connexions between them, may be consistent with the course of evolution, and not merely a consequence of the imperfection of the geological record.

In 1869 H. A. Nicholson described some obscure fossils from the Skiddaw Slates as vegetable impressions: two of them, referred to Hall's genus *Buthotrephis*, were believed to indicate land-plants. Dawson substituted the generic name *Protannularia* in his account of similar fossils from the Devonian of Canada. In both the English and the Canadian specimens the radially-disposed carbonaceous markings on the rock bear a superficial resemblance to the leaf-whorls of the well-known genus *Annularia*. The late Dr. E. A. N. Arber, while fully admitting the doubtful character of the evidence, expressed the opinion that 'it is quite possible that *Protannularia radiata* may be the oldest, in a geological sense, British land-plant'. An examination of Nicholson's type-specimens in the Sedgwick Museum convinces me that any satisfactory determination of their affinity is impossible.

Among the wonderful relics of the rich invertebrate fauna in the Burgess Shale (of Middle Cambrian age) in British Columbia, Dr. Walcott found several specimens which he believes to be the remains of algæ entombed in the mud of a lagoon or small bay in close connexion with the shallow Cambrian sea. Many of th fossils are preserved as shiny black films on the hard shale, and in thin sections of the matrix minute cell-like bodies were seen in chains and groups. Most of the forms described are assigned to the Cyanophyceæ or Blue-Green Algæ, while others are considered to be members of the Red Algæ. The delicate, branched, filamentous form named *Marpolia spissa*, admirably shown on two pieces of shale presented to the Sedgwick Museum by Dr. Walcott, does undoubtedly, as he says, bear a striking superficial resemblance to the recent genus *Cladophora*. By the employment of a very useful method, which will be described elsewhere, my son-in-law (Mr. J. Walton) was able to examine the surface of a piece of the Burgess Shale under the high power of a microscope. He found that the filaments consist of semi-transparent sheaths occasionally broken by transverse cracks into portions which are too irregular in size to be structural: the sheaths show a longitudinal striation due to the presence of one or more narrow, opaque bands. He is inclined to interpret the black threads as filaments of some lowly organized plant similar to the existing *Oscillatoriæ* or other Blue-Green Algæ enclosed in a mucilaginous sheath. Another piece of shale shows an impression of a species of the common Burgess-Shale genus *Morania* represented by impressions of membranous sheets with irregularly scattered perforations; and, as the author of the genus suggests, very similar in texture and general appearance to species of the recent genus *Nostoc*. Chains of small, spherical bodies seen in thin sections of the rock on which *Morania confluens* is preserved are tentatively regarded by Dr. Walcott as remains of the cellular structure of the alga. The evidence is not convincing; but, as Walcott says, it is difficult to conceive of the curved lines of minute balls as inorganic in origin. The Blue-Green Algæ are among the most primitive of living plants, and they live under very diverse conditions, on land, in fresh water, in the sea; they can adapt themselves to higher temperatures than those that are tolerated by the great majority of plants. I recall a striking scene between Northern Australia and Java: broad lines of cinnamon-brown, stretching as far as the eye could see, on the blue surface of the Pacific, consisting of floating

millions of a blue-green alga—*Trichodesmium*. It is in the highest degree probable that similar algæ were among the earlier inhabitants of the Palæozoic oceans.

Several authors have expressed the opinion that the Blue-Green Algæ existed in early Palæozoic times. The attributes of present members of the group encourage the expectation of discovering fossil representatives among the oldest geological records, and such evidence as Dr. Walcott has furnished, although admittedly not conclusive, lends support to inferences based solely on the characters of living plants. Definite evidence has been supplied by Prof. M. D. Zalessky, who found in an Ordovician deposit in Central Esthonia known as Kuckersite (from the locality Kuckers) numerous small aggregates of minute cells with mucilaginous walls, which he compared with colonies of the recent blue-green alga *Gloeocapsa*, and named *Gloeocapsa prisca*. I am indebted to Mr. John Walton for preparations of these bodies, from a sample of Kuckersite generously sent to me by Prof. Zalessky. A Swiss investigator, Dr. H. A. R. Lindenbein, prefers to regard the Ordovician species as a member of a family for which he suggests the designation Protophyceæ, characterized by a combination of certain features now shared by the Blue-Green and Red Algæ. The material which I have examined leads me to think that there is no adequate reason for doubting the correctness of Zalessky's conclusion.

Beneath the waters of some recent lakes there is accumulating a slimy material formed of the partly decomposed remains of small animals and plants of the plankton population. To this material, which contains many spores protected by their resistant membranes, Dr. H. Potonié gave the name sapropel. Certain carbonaceous beds such as boghead, torbanite, and others occurring at various geological horizons are believed to be fossil sapropels: these contain flattened sac-like bodies described by authors as *Pila* and *Rheinschia*, and referred to the Algæ, but by Prof. E. C. Jeffrey identified as spores of Vascular Cryptogams. Although there is a superficial resemblance between the Kuckersite organisms and *Pila* and *Rheinschia*, the former are clearly not sacs like the bodies included in the last-named genera, but irregularly branched cell-aggregates: if not Blue-Green Algæ, they are, I believe, at least closely allied plants, which lived in stagnant lacustrine water during the Ordovician Period.

The Earliest Land-Plants.

We will pass now to consider some of the earliest examples of fossil plants that may reasonably be regarded as the remains of a terrestrial vegetation. Reference has already been made to certain obscure impressions described by Nicholson from the Skiddaw Slates, which, although too imperfect to determine with any degree of confidence, may, as Arber suggested, be the oldest-known relics of a land flora. The records from Silurian rocks are very meagre; but, meagre as they are, they give some weight to the suspicion that precursors of some of the succeeding Devonian types had already established themselves on the land. In the British Museum (Natural History) there are a few specimens of small dichotomously branched axes, with crowded, spirally disposed appendages, from the Lower Ludlow Beds of Staffordshire, which bear a close resemblance to a fossil described by T. G. Halle from rocks of the same age in the island of Gothland. The precise nature of the appendages is not clear: those of the English specimens were probably not true leaves, but slender branches. Halle, in naming the Gothland species *Psilophyton (?) hedei*, tentatively connects it with a genus which is characteristic of older Devonian floras, and was said by Dawson to occur also in Upper Silurian strata in Canada. While it is impossible to establish a definite relationship between Silurian fragments and the Devonian land-plant *Psilophyton*, they certainly suggest a possible alliance.

The small discs known as *Parka decipiens*, though most abundant in Lower Old Red Sandstone rocks in Scotland, may be briefly considered here, as they are recorded also from Upper Silurian localities in England. We are indebted to the late Mr. Archibald Don and to Dr. G. Hickling for the most complete account of this problematical genus. The discs consist of spherical masses of spores enclosed in thin tissue bounded above and below by a covering layer of cells. In a note published in 1921 Mr. W. N. Edwards described two specimens in the British Museum which, he believes, afford some evidence of the attachment of the discs to a stalk: the evidence, though not convincing, is in agreement with an opinion expressed in 1898 that *Parka* was originally attached to a supporting axis. The systematic position of the genus has not been definitely determined: Don & Hickling

considered it to be a Thallophyte with algal affinities; but the fact that the spores were provided with a protective cuticle, and were therefore adapted to dispersal by wind, is in favour of Dr. Hickling's suggestion that *Parka* may be the spore-bearing phase of a plant which grew on lacustrine mud exposed to the air. It may be compared with some existing liverworts, such as *Riccia*. Whether in this Lower Devonian genus we have a complete organism or the spore-bearing portion of some unknown plant, it is of great interest as one of the oldest-known plants that has revealed its minute structure. It existed during the latter part of the Silurian Period, and flourished in the early part of the Devonian: its first appearance coincided, so far as we know, with the earliest stage of the invasion of the land by aquatic plants. The spores of *Parka* may well have been among the first of countless millions of wind-borne plant-dust which has strewn the earth's surface since the arrival of terrestrial vegetation. Although in the grosser features spores of very different races of plants are amazingly alike, their living protoplasm was endowed, in the course of geological history, with ever-changing and widely divergent potentialities.

Devonian Floras.

The Devonian Period demands especial attention, as it introduces us to something more than mere doubtful fragments of terrestrial plants. It is not only the external features of some Devonian fossils that lead us to identify them as dwellers on land; but, in one favoured locality, the wonderful perfection of preservation makes it possible to correlate anatomical characters with the actual conditions governing the life of the plants.

In some regions of the world the piling-up of marine sediments which characterized the earlier Palæozoic Eras was continued in orderly sequence into the Devonian Period. In the western, southern, and central parts of what is now the continent of Europe limestones and other strata rich in marine fossils indicate the presence of a Devonian ocean. It is the records of another phase of Devonian history that claim our attention. Before the close of the Silurian Period movements of the Earth's crust were inaugurated which gradually increased in intensity, and in the earlier part of the Devonian Period culminated in the replacement of wide stretches of the Silurian sea by mountain-ranges. The Caledonian chain connected by a series of lofty summits the

Highlands of Scotland with the Scandinavian peninsula, and continued across the north of Greenland to the arctic lands of North America. The uplifting of previously submerged portions of the earth's crust was the first stage in the change from marine to continental conditions; it is not unreasonable to offer the opinion that it was on these upraised sea-floors that the successful migrants from the ocean entered upon the task of colonizing the land.

The records of Devonian vegetation are often in the form of impressions preserved in sediments deposited some distance from the place where the plants grew. In some localities the presence of roots penetrating the rocks, or the occurrence of stumps of trees with their slender root-like appendages still radiating through the soil, indicates the preservation of vegetation in its original position.

The Essay on Devonian Floras, published after his death, was one of the last of Arber's contributions to the science to which he devoted himself with unflagging zeal and with admirable singleness of purpose. His view was that the older Devonian plants, on the whole, are relics of an extinct group of Thallophyta, exhibiting in their morphological features indications of a transition to the Vascular Cryptogams. Whether one agrees or not with the main contention developed in Arber's treatise—and I cannot but think that, if the author had lived to read the later papers by Kidston & Lang on the Rhynie plants, he would have modified some of the views that he had propounded—one recognizes that it is an able and stimulating addition to palæobotanical speculation, and, incidentally, a very useful compendium of facts. It must, however, be said that the section of the work dealing with the geological age of the Scottish plants needs considerable revision and correction.

In a paper published in 1889 on some Devonian plants from Ohio, J. S. Newberry said:

'While they have given us fascinating glimpses of the head of the column of terrestrial vegetation that has marched across the Earth's stage during the different geological ages, they have given us little insight into the spirit of the movement.'

Since this was written many additional facts have been recorded, the remains of older Devonian floras then unknown have been described, and the discovery of the Rhynie chert-bed has enabled us, not only to acquire an exact anatomical knowledge of certain

Middle Devonian plants, but almost to see them growing as a green carpet slowly spreading over the waters of a marsh-encircled lake. The information thus gained can, in some measure at least, be used as an aid in the interpretation of specimens from other localities preserved as impressions, and in themselves affording little evidence of their true nature.

Newberry's words stimulate the imagination: the realization of the 'spirit of the movement' would give us the clue to the mystery of evolution. This is not an appropriate occasion for a lengthy excursus into the realms of speculative botany; but a few general questions may be briefly considered. What conclusions can be drawn, from a general review of the palæobotanical records furnished by Devonian rocks throughout the world, as regards (1) the measure of the progress of evolution afforded by a comparison of the floras which flourished at different stages of the Devonian period; (2) the geographical distribution of plants during the Devonian Period; and (3) the origin of terrestrial vegetation, and the history of the evolution of the different classes of land-plants?

In 1916 Dr. T. G. Halle expressed the opinion that there is a far greater difference between the Lower Devonian flora of Röragen in Norway and those of Upper Devonian age, than between the latter and the Lower Carboniferous. Arber wrote:

'It is now clear that in Devonian times two terrestrial floras, quite distinct as regards affinity, existed, one in the earlier part, and one in the latter portion of the Devonian Period.'

The former he named the *Psilophyton* Flora, and the latter the *Archæopteris* Flora. The majority of Lower Devonian plants are from the Gaspé Peninsula, Norway, and Scotland; a few are recorded from Belgium, the North of France, the Buland Archipelago off the western coast of Norway, the Falkland Islands, and one species from China. Middle Devonian plants have been described from Canada, a few localities in the Eastern United States, Scotland, Western Norway, Bohemia, and Germany. While some genera are confined to one or other of these two groups of Devonian floras, there is a general similarity of facies in the older Devonian vegetation as a whole. On the other hand, the Upper Devonian floras are not only much richer, but of a different type. One of the richest and best-known later Devonian floras is that of Bear Island within the Arctic Circle. Reference is made later to other floras of this geological age. In more than one region the line between Upper Devonian and Lower Carboniferous

is very difficult to draw, both in the Northern and in the Southern Hemisphere.

The discovery by Dr. W. Mackie, a few years ago, of a bed of chert in Aberdeenshire, almost certainly of Middle Devonian age, may be compared in importance and in its effect upon the imagination with the more recent discovery of the burial-chambers of Tutankhamen in the Valley of the Kings. Subsequent exposure of the Rhynie deposit by the Geological Survey, and the admirable botanical work of Kidston & Lang enable us to reconstruct a Devonian peat-bog; to see the sunlight on the pools of a swamp covered with diminutive green forests, some plants fully exposed to the air, others partly submerged, streams carrying in solution silica furnished by neighbouring fumaroles which was to seal up for us 'after-thoughts of creation,' samples of a peat-forming vegetation and of a microscopic flora of saprophytic fungi, bacteria, and Blue-Green Algæ strangely similar in the plan of their construction to recent forms, yet in certain features bearing the impress of an early phase of evolution. 'The key of the past, as of the future, is to be sought in the present': these words of Huxley find an illustration in the interpretation of the anatomy of fossil plants. The extent of our ability to correlate the structural details of the framework of a living plant, and the activities of which they are the expression, is a measure of accuracy by which we can endow with life the petrified stems from 'the dark backward and abysm of time' and visualize the plants as machines at work.

The Rhynie plants, although not the oldest-known representatives of Devonian vegetation, will be considered first, because our knowledge of them is relatively complete. Excellent summaries of the researches of Kidston & Lang by Dr. D. H. Scott ('Studies in Fossil Botany' 3rd ed. 1920), Prof. F. O. Bower ('Nature' July 29th, 1920), and other authors render it unnecessary for me to do more than call attention to the salient features of this Devonian flora, a flora, be it remembered, which is characteristic of a special physical environment: there may have been other contemporary plant-associations, with very different habitats. The three genera of vascular plants discovered in the Rhynie chert are *Rhynia*, *Hornea*, and *Asteroxylon*. *Rhynia*, represented by two species, was a leafless and rootless plant reaching a height of about

8 inches; from a creeping rhizome were given off slender cylindrical green shoots superficially similar to the leaves of the recent pillwort, but differing in their occasional, regular dichotomy and in the small cylindrical sporangia at the tips of some of the ultimate branchlets. The spores were adapted to dispersal on land. In the creeping stem and the aërial branches was an axial strand of conducting tissue. Simple hairs on the rhizome absorbed material from the peaty soil, and sparsely-scattered stomata on the green erect stems regulated the gaseous exchange between the plant and the surrounding air.

Hornea, although rather smaller, resembled *Rhynia* in habit; but its subterranean stem was a tumid, irregularly-lobed organ, and the terminal sporangia closely resembled the capsules of recent species of *Sphagnum* (the bog-moss), the spores being confined to a region between the wall and a central column of sterile tissue.

Asteroxylon was distinguished from the other two genera by the presence of crowded scale-like leaves on the aërial shoots, a slightly more elaborate conducting strand, and by other characters. *Asteroxylon* was clearly a land-plant; like *Rhynia* it had stomata, whereas the apparent absence of stomata in *Hornea* may mean that it was more aquatic than terrestrial. Associated with the stems of *Asteroxylon* were leafless axes and with them detached sporangia: there is good reason to believe that the leafless forked branchlets were originally prolongations of the leafy aërial stems, and that they bore the sporangia.

These genera raise many interesting botanical problems; but I will confine myself to a brief consideration of the probable position of the Rhynie plants in relation to existing types and to other Devonian fossils. The three genera are included by Kidston and Lang in a group—Psilophytales, so named from the genus *Psilophyton*, described long ago from the Devonian of Canada and recorded from several other regions. In the recent genus *Psilotum*, a widespread Southern Hemisphere member of the group to which our Club Mosses (species of *Lycopodium*) belong, we have a rootless and practically leafless plant similar in general habit to *Rhynia* and *Hornea*, but differing in the structure of the sporangia and in their relation to the rest of the plant-body, as also in some other features. In its leafy shoots, and in the structure of the conducting tissue, *Asteroxylon* presents a closer resemblance to some species of *Lycopodium*; but its sporangia are more fern-like.

Before giving further thought to the Rhynie plants, we will

pass rapidly in review the data gathered from different parts of the world that are available as a basis on which to reconstruct the older Devonian vegetation.

Many Devonian plants have been obtained from different localities between Ohio and the Gaspé peninsula on the south side of the St. Lawrence. During a part of the Devonian Period there was probably an open passage from Gaspé to the south-west through the State of New York and the Southern Appalachians, and in this were deposited sand and mud containing the remains of the vegetation from the marshes and higher ground. Many of the plants found at Gaspé occur on the original soils, and beds of rock are full of their rhizomes. The lower strata at Gaspé contain marine fossils indicating a Lower Devonian age, and with them occur a few drifted plants. Above these are thousands of feet of freshwater sediments rich in plants belonging both to Middle and to Lower Devonian floras. It is interesting to find that the manner of occurrence of some of the Gaspé fossils indicates the former existence of peat-beds with rhizomes still in place, precisely as at Rhynie in Aberdeenshire.

In view of the marked difference between older Devonian floras and those of the Upper Devonian age, it is convenient to consider first the palæobotanical data obtained from Lower and Middle Devonian rocks. My remarks will be confined to few localities and to some of the more interesting and better-known plants. In 1913, Prof. V. M. Goldschmidt discovered plant-bearing beds in a series of barren sedimentary strata, at Lake Röragen in Norway, near the Swedish frontier. In 1916, Dr. T. G. Halle published a full description of the flora, supplementary to a preliminary account previously given by A. G. Nathorst. The plant-beds were probably deposited in a freshwater basin on the Caledonian mountains. A few plant-remains, probably of Lower Devonian age, have also been found on the Island of Sovværet in the Buland Archipelago off the western coast of Norway. Relics of a Middle Devonian flora were described by Nathorst in 1915 from Western Norway, near Nordfjord.

The two richest regions in Europe are Scotland and Bohemia: in the former region much material has been collected from Lower and Middle Devonian strata at widely separated localities, and several plants have been described from Bohemian rocks containing marine Middle Devonian fossils. Other older Devonian localities are mentioned later.

Having given some account of the Rhynie plants, I will now consider the older Devonian floras as a whole.

Many fossils from Scotland and other regions have been erroneously assigned to *Psilophyton*: though a characteristic genus, it is less common than is usually supposed. The generic name has done duty for a variety of plant-fragments, with the result that the importance of Sir William Dawson's account of the type-species has not received its full share of credit. *Psilophyton princeps* Dawson, if I may cite the best-defined species, agrees very closely with *Rhynia* in habit and in its grosser anatomical features: from a horizontal rhizome were given off erect, dichotomously-branched shoots bearing sporangia at the tips of some of the ultimate branchlets. Short spinous appendages, less regularly disposed than ordinary leaves, characterize the erect branches: the spines have been compared with the smaller hemispherical swellings of *Rhynia gwynne-vaughani*, and some authors regard them as simple forms of leaves. A preparation of a piece of a Canadian specimen of *Psilophyton* made by Mr. J. Walton, who recently developed a method of separating the plant-substance from the surrounding matrix, shows very clearly several apparently rigid spines standing erect from the stem and suggesting emergences rather than leaves. Arber believed *Psilophyton* and *Rhynia* to be generically identical. The two undoubtedly are closely allied, as Kidston & Lang have stated; but, for the present at least, the retention of both names is advisable. Mr. W. N. Edwards has succeeded in obtaining a preparation of the carbonized film of a piece of *Psilophyton* which shows epidermal cells and stomata apparently identical with those of *Rhynia*. *Psilophyton* occurs in the older Devonian rocks of Norway, Scotland, Canada, and the North of France: it is essentially characteristic of the Lower and Middle Devonian floras; but, as Dawson believed and Dr. Halle has recently shown, it probably existed in Upper Silurian times. The genus has also been recorded from Upper Devonian rocks, both in France and in North America, but the evidence is not convincing.

It is not my purpose to deal with individual genera in detail; but reference may be made to a form of *Psilophyton* described by Dr. Halle from the Lower Devonian of Norway as *Psilophyton goldschmidti*. This species, in other respects apparently identical with *Psilophyton princeps* Dawson, is characterized by the repeatedly bifurcate lateral branches. One of the problems with

which the botanist is concerned is the origin of the two phyla of plants, which may be styled the Lycopod phylum and the Fern phylum. The Lycopods are essentially microphyllous, while the Ferns are megaphyllous. The Upper Devonian floras contain many plants with large fern-like fronds, and among the older Devonian plants we find examples of branched axes which suggest comparison with the plan of construction of a large fern-leaf, except in the absence of leaflets. The question is, were the Ferns and Lycopods both the offspring of a common ancestor, or do they represent separate lines of evolution? Dr. Halle suggests that the views of O. Lignier may be considered to derive some support from certain old Devonian types. It may be, as Lignier believed, that the small Lycopod leaf arose as a mere emergence such as we see foreshadowed in *Psilophyton*, and retained in the living *Psilotum*; while the compound Fern-frond traces its evolution to a modified branch-system on which numerous flat leaflets were subsequently developed. The combination in *Psilophyton goldschmidti* of the spinous appendages on the main stem and the bifurcate spineless branches may be regarded as symptomatic of a common origin of the microphyllous and megaphyllous form of foliage. In many living Ferns we see, as Halle points out, a similar combination of the small scale-like leaf without chlorophyll clothing the rhizome, the homologue of the green leaf of *Lycopodium*, and the large green frond derived from a system of branches of some early precursor, such as the bifurcate lateral branches of *Psilophyton goldschmidti*. On the other hand, there is a danger of over-estimating the importance of resemblances between the form of branching in one plant and that in another. The line of evolution of Lycopodiaceous plants is, I think, clearly indicated; and we have no adequate reason for assuming any meeting-place between the Fern and the Lycopod phyla. Among the earlier terrestrial plants parallelism of development may safely be postulated: the fronds of Ferns were probably derived direct from the thallus of some algal ancestor, unconnected with that which produced the small-leaved Lycopods.

An extinct plant combining in the sum of its characters morphological features which no longer occur together in the same family or group is usually considered to be, if not a 'missing link', at least a signpost on the evolutionary road pointing the way to some ancestral stock whence were derived descendants which

gradually lost the impress of a common parentage. A well-known example of such a generalized type used to be the so-called Seed-bearing Ferns or Pteridosperms, which were a prominent feature in the forests of the Coal Period. It was believed that the Fern phylum was the source of all Seed-plants. The majority of us, in different degrees, shared this belief. Opinion has now altered. Dr. D. H. Scott, who formerly supported the old view, has changed his mind—men who never change their minds are, as William Blake quaintly but truthfully expressed it, like stagnant water, and 'breed reptiles of the mind'. Dr. Scott has recently written:—

'The inference from all the facts at present available appears to be that the Seed-plants, of which the Pteridosperms are among the earlier representatives, constitute an independent phylum, of equal antiquity with any of the recognized lines of Vascular Cryptogams.'

The Middle Devonian *Asteroxylon*, its stem-anatomy and habit essentially Lycopodiaceous, its sporangia more akin to those of Ferns, might also be quoted as a generalized type suggesting a common origin for the two groups; on the other hand, its Fern-like sporangia may merely illustrate a variation from the normal Lycopodiaceous pattern, reproducing a type of construction adopted as a permanent possession by the independently evolved Fern alliance. Dr. Church, in his Essay on 'Thalassiophyta & the Subaërial Transmigration,' lays stress on the isolation of the modern representatives of the great sections of the plant-kingdom, and contends that schemes of linkage between the different lines of development are wholly fallacious. All the various lines of development of what is now land-flora, he believes, must have been 'differentiated in the Benthic epoch of the sea (*i.e.*, on algal lines)', as all algal lines were differentiated in the Plankton phase. The occasional occurrence in one type of plant of features characteristic of different groups is, in itself, no adequate reason for assuming community of descent. In the earlier, more experimental stage of evolution, the plasticity of plants belonging to different lines of development would inevitably sometimes find similar expression. The potentiality of protoplasm is the determining factor, and it would seem more logical to picture the unfolding of the several groups of the plant-kingdom as so many distinct processes governed by the forces enclosed within the cells of diverse marine prototypes, than to assume the wholesale destruction of common ancestors demanded by those who prefer to link into one complex of infinite resource the several sections of the plant-world.

The broader spinous stems first described by Sir William Dawson from the Lower Devonian of Gaspé as *Arthrostigma gracile*, recorded by Dr. R. Kidston from beds of similar age in Perthshire, and more recently by Dr. T. G. Halle from the Lower Devonian flora of Röragen and from China, clearly belong to a plant which, if not generically identical with *Psilophyton*, is nearly allied to it. A relatively slender vascular axis occupied the centre of the stem, and on the surface were spine-like leaves or emergences, arranged either spirally or in whorls. Occasional lateral branches were given off at a wide angle, and then bent abruptly upwards parallel to the main axis, a habit analogous to that of some succulent Euphorbias, plants which in some other respects recall the Devonian genus. Specimens apparently of the same generic type as *Arthrostigma* have been described from the Middle Devonian of Bohemia; but the genus is characteristic of the earliest Devonian floras.

Reference has already been made to the occurrence in both Lower and Middle Devonian beds of dichotomously-branched slender axes similar to those described from Bohemia as species of *Hostimella*. A characteristic feature of these fossils is the occurrence of a bud-like structure close to the point of bifurcation: it has been suggested that this is actually an aborted bud; and in this connexion it may be noted that other slender axes from beds of the same age, but with a different disposition of lateral branches, frequently bear more than one branch at the same point on the major axis. The type to which I refer resembles some of the specimens referred by Nathorst to the genus *Aphyllopteris*, and similar fossils are included in *Zosterophyllum*. These various forms of branched axes cannot be assigned with any degree of confidence to a systematic position: the *Hostimella* type resembles the lateral branch-systems of *Psilophyton goldschmidti*; while that of the *Aphyllopteris* type may be compared with specimens from Middle Devonian rocks in Germany described, on good grounds by Solms-Laubach as portions of a large Fern-frond without leaflets, and with undoubted fern raches from Upper Devonian rocks.

The comparatively-large branched axis, described by J. W. Salter from Devonian beds at Thurso as *Caulopteris peachii*, differs from any of the older Devonian Psilophytales, and bears a close resemblance to the stems of certain Ferns and to those of

some Carboniferous Pteridosperms. We know nothing of its internal structure, and there are no adequate grounds on which to assume a relationship to the true *Caulopteris* of the Coal Measures. Dr. Kidston is of opinion that the more slender stems bearing curved and (presumably) partly expanded branches clothed with filiform appendages, which Dawson named *Psilophyton thomsoni* and by some authors have been confused with *Thursophyton*, belong to Salter's *Caulopteris*. Specimens described by H. Potonié and C. Bernard from the Middle Devonian of Bohemia as *Spiropteris hostimensis* are, in all probability, generically identical with the *Psilophyton* from Scotland. The main interest of these little understood fossils is that their habit is Fern-like: they may be early representatives of the Filicinean stock.

In *Rhynia*, *Hornea*, *Psilophyton*, and *Arthrostigma* we have a group of fossils without doubt closely related one to the other; but the degree of relationship must be left, for the present, undecided. *Rhynia* and *Hornea* are of Middle Devonian age; *Psilophyton* and *Arthrostigma*, though mainly Lower Devonian genera, occur also in Middle Devonian rocks. In 1907 Dr. David White described a remarkable fossil tree, from Upper Devonian beds near Naples in New York County, which he named *Archæosigillaria primæva*: it has more recently been assigned by Mr. E. W. Berry, and with good reason, to the genus *Protolepidodendron*. The stem, when first discovered, was about 16½ feet in length, with no branches; although, as Berry indicates in his restoration of the Naples tree, it probably branched nearer the summit. On some parts of the stem the surface-features recall those of some Sigillarias, and in others there is a closer resemblance to certain Lepidodendra: the lower portion of the trunk is characterized by fairly regular and prominent longitudinal ridges, and the base is swollen like that of a Royal Palm. The leaves, about 3 cm. in length, are of the Lycopod form. Slender rootlets penetrate the soil from the bulbous base of the stem.

We may next turn to some stumps of trees recently discovered in strata (stated by Dr. J. M. Clarke to be of Middle Devonian age) near the village of Gilboa, a locality about 200 miles from Naples (N.Y.). The complete stems may have reached the length of 20 to 30 feet and a diameter of 2 feet. The lower end of the stem was continued downwards into a swollen base bearing rootlets. Dr. Clarke states that some of the narrow, strap-like leaves bore a

pair of sporangia, but of their structure we know nothing. I take this opportunity of thanking him for giving me information about the specimens and their geological age.

It is clear that in some parts of the world there existed arborescent Lycopodiaceous plants comparable in some respects to the much smaller *Rhynia*, *Hornea*, and *Psilophyton*. We may go farther, and express agreement with Dr. Halle's view that between the older Devonian Psilophytales and the widespread Upper Devonian *Cyclostigma* there is a very close alliance. It is, I venture to think, probable that in the swollen bases of the Naples and Gilboa trees we have a feature connected by descent with the tuberous rhizome of *Hornea*, and on the other hand with the Stigmarian 'roots' of *Sigillaria* and *Lepidodendron*. It is noteworthy that anatomically *Stigmaria* differs from the erect Sigillarian or Lepidodendroid stems in the absence of the characteristic cylinder or solid strand of primary vascular tissue: may this difference be interpreted as a consequence of the developmental history of *Stigmaria*? The tuberous rhizome of *Hornea* has no vascular supply of its own: when it increased in size, and a vascular system became essential, the need may have been met by the production of a cylinder mainly composed of secondary conducting tissue.

Many remains of Lepidodendroid plants have been recorded from the Southern Hemisphere. In the Falkland Islands Dr. Halle, and subsequently Dr. H. A. Baker, found fragments of stems, superficially at least very similar to some specimens of *Arthrostigma* from Norway and of *Protolepidodendron* from Bohemia, as also to the later Cyclostigmas: the beds are probably either Lower or Middle Devonian. Many examples of Lepidodendroid remains have been described from the Witteberg Series of South Africa, and recently M. F. F. Mathieu generously sent to me similar specimens from the Belgian Congo. Others have been recorded from Upper Devonian and Lower Carboniferous rocks in Australia. The conclusion is that, during the Devonian Period, the Lycopod phylum was in vigorous development, and its representatives were geographically widespread. In the size of the individuals, and in the range of form and structure, this phylum reached its maximum during the latter part of the Carboniferous Period.

Reference may be made here to a characteristic Middle Devonian

plant named by Nathorst *Thursophyton*, and often confused with *Psilophyton*. *Thursophyton* is the plant called by J. W. Salter *Lycopodites milleri*, and by W. Carruthers *Psilophyton dechenianum*; it is, as Kidston & Lang have stated, almost certainly identical with *Asteroxylon* from Aberdeenshire. In *Thursophyton* the distinguishing feature is the possession of imbricate scale-like leaves, in place of the spinous appendages of *Psilophyton*: it is another of the earlier Lycopodiaceous genera.

Several years ago some casts of longitudinally-ribbed stems were described, from Lower Devonian rocks in the Shetland Islands, as possible allies of the genus *Calamites*. The largest specimen that I have seen is one in the Edinburgh Museum, 48 cm. long and 13 cm. in diameter. Similar ribbed stems have been found at both Lower and Middle Devonian localities on the mainland of Scotland, and they are often spoken of as the 'Corduroy Plant.' It is possible that these casts may belong to plants similar to the large *Protolepidodendra* from Naples and Gilboa: a regular ribbing characterizes the lower parts of those stems, and on some specimens of *Cyclostigma* from the Upper Devonian of Ireland and Bear Island precisely similar ribs are not infrequent.

There are many other plant-remains from Middle Devonian floras, especially from Bohemia, which cannot be dealt with in a general survey; but a comparison of the illustrations given by Potonié & Bernard with specimens from the older Devonian rocks of Scotland convinces me that there is a strong likeness between the two floras. From Western Norway Nathorst has described two new genera, *Bröggeria* and *Hyenia*; the former, represented by branched axes bearing relatively long terminal clusters of sporangia, may be a forerunner of the Upper Devonian type illustrated by such a genus as *Archæopteris*. *Hyenia*, as Nathorst suggests, would seem to be related to the Sphenophyllales.

The older Devonian floras are, in the first place, characterized by the relative abundance of members of the Lycopod phylum: some leafless and rootless like *Rhynia* and *Hornea*; some, like *Asteroxylon* and the impressions represented by *Thursophyton*, with crowded scale-like leaves; others in which spine-like appendages—as in *Psilophyton* and *Arthrostigma*—took the place of normal leaves; and some arborescent forms having leaves and leaf-scars more akin to those of the later Lepidodendra and a swollen rootlet-

bearing base to their stems. With these were plants of which we have less knowledge, foreshadowing in the plan of their branching the ferns of a later age, but for the most part characterized by the absence of foliar appendages provided with a flat lamina. Stems of ferns with the vascular tissue preserved are known from the Upper Devonian of Canada and Australia; branched axes identical, except in the absence of leaflets, with the fronds of typical ferns are recorded from Middle Devonian horizons; but from the older Devonian localities very few examples have been discovered of organs with a flat lamina. Specimens described by Nathorst from Middle Devonian rocks in Western Norway as *Psygmophyllum kolderupi* show wedge-shaped laminæ, attached to slender branches which resemble the leaflets of *Archæopteris*: it is not clear whether they are simple leaves, or leaflets of a compound frond. A specimen in the British Museum (Natural History) from the Middle Devonian of Caithness bears a close resemblance to an Upper Devonian species named by Dawson *Platyphyllum brownianum*, and in shape agrees with the genus *Psygmophyllum* as represented in the Upper Devonian flora of Spitsbergen and in the Carboniferous floras of different regions. Dr. David White considers that Dawson's *Platyphyllum* is probably algal, and not a true leaf. The Caithness fossil, although it may be a leaf, shares with the Canadian specimens the possession of delicate vein-like markings which do not suggest true vascular strands. If we are correct in assuming that the majority of the older Devonian plants so far described grew on low-lying or swampy ground, the possibility must be admitted that in situations less favourably placed for the preservation of samples of the vegetation, and under other physical and climatic conditions, there may have lived representatives of a higher type of organization—plants with more woody and less succulent stems, comparable with the Gymnosperms of Upper Devonian floras. So far as I am aware, there is as yet no thoroughly satisfactory evidence of the existence prior to Upper Devonian times of any undoubted Gymnosperm. Dr. D. H. Scott has emphasized the importance of bearing in mind the fossil stem called by W. R. McNab *Palæopitys milleri*, from the Middle Devonian of Cromarty, and often spoken of as a Conifer. A piece of the specimen originally described by Hugh Miller is being investigated by Dr. R. Kidston & Prof. W. H. Lang; and meanwhile I can only state that the former tells me that the structure is not that of a typical Gymnosperm. J. S. Newberry described

some wood from rocks stated to be of Middle Devonian age in Ohio, which is undoubtedly of the Gymnospermous type; but Dr. Scott informed me that Dr. H. M. Ami assigns the Ohio beds to an Upper Devonian horizon. In 1895 Count H. Solms-Laubach described a small piece of petrified stem from the Lenne Shales of Gräfrath, of Middle Devonian age, showing radially disposed wood-elements and strips of medullary-ray tissue, which, he suggested, might perhaps belong, either to a plant allied to the *Lyginopteris* family, or to a member of the Calamarieæ. The specimen is clearly a fragment of a stem capable of secondary growth in thickness; but we cannot determine its precise affinity.

We have seen that the older Devonian floras included certain plants which were trees in stature, and there are indications that some of the terrestrial species had solved the problem of secondary increase in girth. One of the outstanding features in the architectural plan of Palæozoic vegetation is the widespread occurrence of the arborescent habit. On several lines of evolution the method of adding to the diameter of stems and branches by means of an ever-young cambium-cylinder was adopted at an early period in the history of the vegetable kingdom. Ability to increase the number of branches and the area of the foliage, which is an attribute only of plants that can also meet the consequent rise in the demand for water and manufactured food by supplying additional means of transport, is a conspicuous feature of several different families in the Palæozoic floras. While some of these plants belonged to lines of evolution which cannot be directly connected with any surviving forms, others, which possessed this capacity of unlimited expansion, belong to classes the modern representatives of which are herbaceous in habit, and a limit is set at an early age to further increase of the tissues concerned with water- and food-conduction.

Until some well-defined type of Gymnospermous plant is discovered, I prefer to think of the older Devonian floras as chiefly composed of relatively simple representatives of the Lycopod and Filicinean phyla, plants which were adapted to conditions not very far removed from an aqueous habitat. Some may have grown in water, while others flourished in swamps where the composition of the soil rendered essential economy in transpiration, a circumstance which was reflected in the general absence of thin and well-developed leaves. In the succeeding Upper Devonian period a

type of vegetation became dominant, which not only marked a striking advance in organization and in variety, but was no longer hampered by the exigencies of swamp conditions. Trees with a highly-differentiated mechanism, at least equal to that of recent Conifers in the complexity of structure, were not uncommon; and there is no reason to doubt their ability to respond to the demands of relatively dry habitats.

Our knowledge of Devonian vegetation in the Southern Hemisphere is very imperfect. No undoubted examples of such characteristic northern genera as *Psilophyton* and *Thursophyton* are recorded, but too much weight may easily be given to this negative evidence. It is not improbable that the older Devonian rocks of the southern continents so far explored were formed under conditions ill adapted to the preservation of peat-forming associations. Reference has already been made elsewhere to the fairly frequent occurrence in African deposits (some of which are either of Lower or of Middle Devonian age, and others probably Upper Devonian) of pieces of stems similar in external features to *Protolepidodendron*, a Middle and Upper Devonian genus in North America and Europe, to *Cyclostigma*, a characteristic Upper Devonian genus, and exhibiting some resemblance to certain forms of the older *Arthrostigma*. Attention should also be drawn to a specimen figured by Dr. T. G. Halle from rocks in the Falkland Islands, either Lower or Middle Devonian, as an indeterminable stem-fragment: since the publication of Halle's paper the genus *Hornea* has been discovered, and Halle himself has described a similar type (*Sporogonites exuberans*) from Lower Devonian rocks in Norway. A terminal globular swelling on the fragment from the Falkland Islands shows a clear differentiation of a central region and a more solid peripheral region, precisely as in the spore-capsules of *Hornea* and *Sporogonites*. I may say that Dr. Halle agrees with me that the resemblance is probably significant. Available information does not warrant the assumption that the older Devonian floras in the south were different in facies from those in the north.

In South Africa the Cape System includes a very considerable thickness of sedimentary strata, largely unfossiliferous, and in part (it is believed) formed under more or less arid conditions. Resting upon the pile of almost completely barren sandstones of the Table

Mountain Series is the Bokkeveld Series, in which older Devonian marine fossils have been discovered, and, in the upper part, some remains of Lepidodendroid plants. Several specimens of similar Lepidodendroid plant-fragments are recorded from the overlying Witteberg Series, some of them closely resembling stems of *Cyclostigma* from the Upper Devonian flora of Bear Island and other regions. In the Witteberg Beds of Cape Colony the problematical fossil *Spirophyton* is a characteristic feature: as Dr. A. W. Rogers & Dr. A. L. du Toit say,—'whether a true fossil or not, *Spirophyton* has been found of great service in enabling the Witteberg Beds to be recognized'. The type-species, *Spirophyton cauda-galli*, first described from Devonian rocks in North America, occurs under various forms in strata ranging in age from Silurian to Tertiary. I have elsewhere discussed its nature, and expressed the opinion that it is of inorganic origin. Specimens recently shown to me by Dr. R. Kidston, which were obtained from Lower Carboniferous strata in Scotland, differ from the great majority of previously discovered examples in having the surface covered with a thick film of coal: while it is possible that the carbonaceous matter came from some other source, it affords an argument favourable to the view of several authors that *Spirophyton* owes its occurrence to some large marine Alga.

Various fossil plants have been described from Australian rocks assigned by some geologists to an Upper Devonian age, but by others classed as Carboniferous. From certain localities Devonian plants have undoubtedly been obtained. The species usually known as *Lepidodendron australe* M'Coy occurs in both Devonian and Carboniferous rocks: it is closely allied to some of the Upper Palæozoic *Lepidodendra* of the Northern Hemisphere.

Time does not admit of a consideration of the oldest Australian flora; but I would draw attention to a close resemblance between some plant-remains described by W. S. Dun from strata in New South Wales said to be Upper Devonian as *Pecopteris* (?) *obscura*, and the Upper Devonian plant from Maine named by Dr. David White *Barinophyton richardsoni*. There is no doubt that, before the close of the Devonian Period, plants which appear to be generically identical had spread from well within the Arctic circle to the latitude of Southern Australia.

A remarkable feature of the Upper Devonian floras is the high

degree of differentiation and the variety of the genera. It will, however, be more appropriate and more convenient to consider the composition of these floras when we follow the history of the vegetation of the world through the closing scenes of the Palæozoic Era. Meanwhile, I shall content myself with a brief reference to the distribution of the genus *Archæopteris.* The type-species, described by Edward Forbes in 1852 from the Upper Devonian rocks of Kilkenny as *Cyclopteris hibernica,* was renamed by Sir William Dawson *Archæopteris hibernica*: it is represented by large, compound, fernlike fronds similar in habit to those of certain recent species, and characterized by its cuneate leaflets and dense clusters of sporangia. We are still in doubt as to the precise systematic position of the genus; like recent Ferns, it may have possessed spores of one kind only, or, on the other hand, it may be a member of the extinct group of Pteridosperms. The several species are distinguished by relatively slight differences in the size and degree of dissection of the leaflets. *Archæopteris* is recorded from Upper Devonian strata in Ellesmere Land, Bear Island, Canada, Pennsylvania, Berwickshire, Ireland, Belgium, Germany, Russia, Australia, and elsewhere. The occurrence of *Archæopteris* and other genera as far north as lat. 80° N. and in Bear Island, where the flora seems to have been at least as rich and vigorous as in the South of Ireland, is a remarkable fact that raises climatic problems, of which as yet no satisfactory solution has been found. It is difficult to picture these plants completing their life-histories in the brief span of an Arctic summer: we talk glibly of sub-tropical or even tropical conditions in far northern regions, without sufficiently realizing the difficulties from the point of view of the plants. Admitting the probability of the assumed existence of a higher temperature than was actually required by the plants discovered in Polar lands, the problem of the Arctic night and its effect upon the vegetation still remains. We have much to learn from experimental work about the ability of plants to endure the long alternating periods of continuous illumination and comparative darkness, and we are hardly in a position to demand as a necessity either a shifting axis or a wandering crust.

The differences between the older and the Upper Devonian floras may well be connected with differences in environment, as well as with the march of evolution. Before the end of the Devonian Period the terrestrial vegetation had come into its own, and had colonized the higher and drier ground in addition to the

marshes and peat-bogs. A change in the geological background had its reflex in the development of green foliage in place of the almost leafless condition of the older plants, destined to live in localities either physically or physiologically dry.

Here I must leave for the present the too ambitious subject, which has been very inadequately treated. We have reached a stage in the history of the plant-kingdom which in essentials persisted until the latter part of the Carboniferous Period, when, in correlation with a changed historical background, there was an apparently sudden burst of energy, and new companies of actors carried on the drama. With your permission, and if circumstances permit, I will endeavour on a future occasion to follow the development of plant-life through the closing scenes of the Palæozoic Era, and, as far as it is possible to do so, consider the relation of the succeeding Mesozoic floras, both to those which preceded them and to the vegetation of the modern world.

February 28th, 1923.

Prof. A. C. Seward, Sc.D., F.R.S., President, and afterwards Prof. W. W. Watts, Sc.D., F.R.S., Vice-President, in the Chair.

Aubrey Ward Guest, New Oxford & Cambridge Club, Piccadilly, W. 1; Thomas Hitchon, c/o Finlay, Fleming & Co. Ltd., Burmah Oil Company Ltd., Rangoon (Burma); and Errol Ivor White, B.Sc., Assistant in the Geological Department of the British Museum (Natural History), 82 Amhurst Park, N. 16, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Late-Glacial Stage of the Lea Valley (Third Report).' By Samuel Hazzledine Warren, F.G.S.

2. 'The *Elephas-antiquus* Bed of Clacton-on-Sea (Essex), and its Flora and Fauna.' By Samuel Hazzledine Warren, F.G.S. and others.

Lantern-slides, fossils, and implements were exhibited in illustration of Mr. S. H. Warren's papers.

March 14th, 1923.

Prof. A. C. Seward, Sc.D., F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Geology of the Schists of the Schichallion District of Perthshire.' By Ernest Masson Anderson, M.A., B.Sc., F.R.S.E., F.G.S.

2. 'The Petrology of the Arnage District in Aberdeenshire: a Study of Assimilation.' By Herbert Harold Read, M.Sc., F.G.S.

Rock-specimens and lantern-slides were exhibited in illustration of the papers by Mr. E. M. Anderson and Mr. H. H. Read.

March 28th, 1923.

Dr. Herbert H. Thomas, M.A., Vice-President,
in the Chair.

Ernest St. John Burton, Melville, Howard Road, Bournemouth (Hampshire); Robert Claytor, Thurnscoe Hall, near Rotherham (Yorkshire); Annie Ethel Cook, B.Sc., 8 Church Lane, Hornsey, N. 8; the Rev. Charles William Cooper, St. Paul's Vicarage, Northampton Park, Canonbury, N. 1; and James Frederick Jackson, 18 Elm Street, Cardiff, were elected Fellows of the Society.

The Chairman announced that the Proceeds of the Daniel-Pidgeon Fund for 1923 had been awarded to Howel Williams, B.A., M.Sc., of the University of Liverpool, who proposes to investigate the stratigraphy and vulcanicity of Snowdon.

The following communication was read:—

'Further Researches on the Succession and Metamorphism in the Mona Complex.' By Edward Greenly, D.Sc., F.G.S.

Dr. Greenly exhibited lantern-slides, microscope-slides, and rock-specimens, in illustration of his paper.

April 18th, 1923.

Prof. A. C. Seward, Sc.D., F.R.S., President, and afterwards Dr. Herbert H. Thomas, M.A., Vice-President, in the Chair.

The List of Donations to the Library was read.

The following communication was read:—

'The Structure of the Bowmore-Portaskaig District of Islay.' By John Frederick Norman Green, B.A., F.G.S.

Microscope-sections and rock-specimens were exhibited by Mr. Green, in illustration of his paper.

May 2nd, 1923.

Prof. A. C. Seward, Sc.D., F.R.S., President,
in the Chair.

Frank Higham, B.Sc., A.R.S.M., 57 Widdrington Road, Coventry; and Marie Vobe, Roselea, Abbey Wood Road, Abbey Wood, S.E. 2, were elected Fellows of the Society.

The List of Donations to the Library was read.

Prof. John Joly, D.Sc., F.R.S., F.G.S., then proceeded to deliver a lecture on the Bearing of some Recent Advances in Physical Science on Geology.

After referring to the discovery by the present Lord Rayleigh of the general distribution of radioactive materials and to the earlier but more recently developed discovery of isostasy, the Lecturer observed that, assuming that the dense layer upon which, according to the theory of isostasy, the continents float, is composed of basalt possessing the average radioactivity of basalts, it may be calculated that, if this substratum is now solid (as appears from both tidal and seismological evidence), it will have acquired sufficient radioactive heat to become fluid in about 30 million years.

The change of density then occurring will cause a downward motion of the continents relative to the ocean, and transgressional seas will result. After a long period, during which the liquid magma (under tidal forces) circulates from beneath the continents (which, owing to their own radioactivity, act as an adiatherminous covering) to suboceanic regions, the accumulated heat is given up to the ocean. Re-solidification of the magma ensues, and the restoration of the former higher density causes the continents to rise relatively to the oceans, and brings about the retreat of transgressional seas. In this manner, the complete cycle of a revolution finds explanation.

Mountain-building forces arising during the climax of revolution originate from two sources:—(*a*) the effects of the horizontal tide-generating force and of precessional force which, although probably considerable, have not yet been evaluated; (*b*) the effects of the changing area of the ocean-floor attending the expansion and contraction of the basaltic layer, whereby the oceanic area becomes alternately increased and diminished. Upon shrinkage the enlarged ocean-floor bears against the continents. Hence 'the highest mountains confront the widest oceans'.

Mountain-building is due much more to vertical than to horizontal forces. The mountains are not pushed up by lateral forces: these forces act upon the subsiding geosyncline to produce deformation of the semi-plastic materials. The mountains are elevated

long after by the isostatic forces, the energy being traceable to the stored radioactive heat of prior ages.

Inter-revolutionary events consist of 'preparatory' disturbances, due to local increase of liquefaction of the magma: also of 'sequential' disturbances, due to relief of strain accumulated during revolution, and to the restoration of isostatic equilibrium.

The conditions now prevailing beneath the continents preclude the establishment of a steady state (that is, of thermal equilibrium), and in the past always must have done so.

The cyclical events outlined in the theory here adduced appear to be inevitable as a consequence of radioactivity and isostasy. Cyclical disturbances alone can explain the past history of the Earth's surface.

A cordial vote of thanks was unanimously accorded to the Lecturer by the Fellows present.

May 16th, 1923.

Prof. W. W. Watts, Sc.D., F.R.S., Vice-President, in the Chair.

Harold Francis Banks, Chase Road, Burntwood, near Lichfield (Staffordshire); Arthur Delmar Combe, Geological Survey of Uganda, Entebbe (Uganda); and Robert Murray-Hughes, Sable Antelope Mine, Mumbwa (Northern Rhodesia), were elected Fellows of the Society.

Prof. Lucien Cayeux, 6 Place Denfert-Rochereau, Paris XIVème; Prof. John M. Clarke, LL.D., Director of the New York State Museum, Albany (N.Y.), U.S.A.; Prof. Henri Douvillé, 207 Boulevard Saint-Germain, Paris VIIème; and Prof. Waldemar Lindgren, Massachusetts Institute of Technology, Boston (Mass.), U.S.A., were elected Foreign Members of the Society.

Prof. Emile Argand, University of Neuchâtel (Switzerland); Prof. Léon William Collet, University of Geneva (Switzerland); Prof. Reginald Aldworth Daly, 23 Hawthorn Street, Cambridge (Mass.), U.S.A.; Prof. G. Delépine, 13 Rue de Toul, Lille (Nord), France; Prof. Paul Fourmarier, 140 Avenue de l'Observatoire, Liége (Belgium); Prof. Victor Moritz Goldschmidt, Universitetets Mineralogisk Institut, 23 Trondhjemsveien, Christiania (Norway); Prof. Thore Gustafsson Halle, Naturhistorisk Riksmuseum, Stockholm 50 (Sweden); Prof. James Furman Kemp, Columbia University, New York City, U.S.A.; Prof. Carl Frederik Kolderup, University of Bergen (Norway); Prof. Carlos I. Lisson, Escuela de Ingenieros, Lima (Peru); Prof. Gustaaf Adolf Frederik Molengraaff, 60 Voorstraat, Delft (Holland); Dr. Armand Rénier,

Directeur du Service Géologique de Belgique, Palais du Cinquantenaire, Brussels (Belgium); Prof. Pierre Termier, Directeur des Services de la Carte Géologique de France, 164 Rue de Vaugirard, Paris XVème; and Dr. Frederick Eugene Wright, Geophysical Laboratory, Washington (D.C.), U.S.A., were elected Foreign Correspondents of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Upper Ordovician Rocks of the South-Western Berwyn Hills.' By William Bernard Robinson King, O.B.E., M.A., F.G.S.

2. 'The Geology of the District around Corris and Aberllefenni (Merioneth).' By Prof. William John Pugh, O.B.E., B.A., F.G.S.

Specimens were exhibited by Mr. King, in illustration of his paper; and specimens and lantern-slides were exhibited by Prof. Pugh, in illustration of his paper.

June 6th, 1923.

Prof. W. W. Watts, Sc.D., F.R.S., Vice-President, in the Chair.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On a New Blattoid Wing from the Harrow Hill Mine, Drybrook (Forest of Dean).' By Herbert Bolton, D.Sc., F.R.S.E., F.G.S.

2. 'Contact-Metamorphism in the Comrie Area of the Perthshire Highlands.' By Cecil Edgar Tilley, Ph.D., B.Sc., F.G.S.

Lantern-slides, etc. were exhibited by Dr. H. Bolton; and rock-specimens, microscope-sections, and lantern-slides were exhibited by Dr. C. E. Tilley, in illustration of their respective papers.

June 20th, 1923.

Prof. A. C. Seward, Sc.D., F.R.S., President,
in the Chair.

Thomas Sutton Bowman, B.Sc., c/o the Petroleum Office, Ministry of Finance, Dawawin P.O., Cairo (Egypt); Christopher Theodore Augustine Gaster, 23 St. John's Terrace, Lewes (Sussex); William Henry Kirkby, M.A., 401 Gillott Road, Edgbaston, Birmingham; Edwin Godwin Thomas, Pen-yr-Heol, Ferndale (Glamorgan); and Joseph Chatten Vivian, Tharsis Sulphur & Copper Company, Ltd., Agencia de Tharsis, Apartado 19, Huelva (Spain), were elected Fellows of the Society.

The List of Donations to the Library was read.

The Names of certain Fellows of the Society were read out for the first time, in conformity with the Bye-Laws, Sect. VI, Art. 5, in consequence of the non-payment of the arrears of their Annual Contributions.

Miss P. de B. F. Bowen-Coulthurst presented a geological hammer, chisel, and satchel formerly belonging to George Bellas Greenough, first President and one of the founders of the Society. She also presented a number of valuable documents and minute-books of great historical and scientific interest, forming part of the earliest records of the Society's activities.

Dr. Herbert H. Thomas, M.A., V.P.G.S., gave a demonstration of the Source of Origin of the Stones of Stonehenge, illustrated by lantern-slides.

The following communications were read:—

1. 'The River-Gravels of the Oxford District.' By Kenneth Stuart Sandford, B.A., F.G.S.; with an Appendix on the Non-marine Mollusca, by Alfred Santer Kennard, F.G.S., and Bernard Barham Woodward, F.L.S., F.G.S.; and an Appendix on the Mineral Analyses of the Clay and Sand Deposits of Wolvercote, by R. C. Spiller, B.A.

2. 'The Deposits of Paleocene Mammalia in Belgium.' By Prof. Louis Dollo, Sc.D., For.Mem.G.S., and Prof. P. Teilhard de Chardin, D.Sc.

Dr. G. T. Prior, M.A., F.R.S., exhibited a meteoric stone which fell at Ashdon, near Saffron Walden (Essex), on March 9th, 1923.

Dr. L. L. Fermor exhibited microscope-slides of cordierite from Indian 'para-lavas', pleochroic in thin section, in illustration of his remarks on Dr. C. E. Tilley's paper (read on June 6th).

Implements, fossil-remains, and lantern-slides were exhibited by Mr. K. S. Sandford, in illustration of his paper.

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1. NOTES *on the* PHOSPHATE DEPOSIT *of* OCEAN ISLAND; *with* REMARKS *on the* PHOSPHATES *of the* EQUATORIAL BELT *of the* PACIFIC OCEAN. By LAUNCELOT OWEN, A.R.S.M., A.R.C.S., F.G.S. (Read December 21st, 1921.)

CONTENTS.

I. INTRODUCTION.

WITHIN the tropical belt of the Pacific Ocean occur several islands containing deposits rich in calcium phosphate. The majority of these islands are situated within 10° of the Equator, and between longitudes 140° E. and 180° E.

At the present day, the islands the deposits of which may be considered as of commercial importance are Angaur, Makatea (near Tahiti), Nauru, and Ocean Island. Other islands, most of which have been worked in the early days of the phosphate industry, are Baker, Howland, Phœnix, Sydney, Malden, Christmas,

Flint, Starbuck, Browse, Lacépède, Laysan, Cornwallis, and Clipperton.

Although from time to time various theories have been put forward as to the origin of these phosphate deposits, there can be no reasonable doubt that they are all due, primarily, to bird-droppings.

With the one exception of Clipperton Island, the deposits consist entirely of more or less leached guano overlying a coral-floor which is, to a greater or less extent, changed by metasomatism into tricalcium phosphate. The deposits mentioned as being of commercial importance have been leached so completely that the soluble phosphates have entirely disappeared, some of the phosphate on Ocean Island, for example, containing over 90 per cent. of tricalcium phosphate ($Ca_3P_2O_8$). On Malden Island, where the birds still congregate, all three forms of calcium phosphate ($CaH_4P_2O_8$, $CaHPO_4$, and $Ca_3P_2O_8$) are found; while on Clipperton Island[1] a mass of trachyte, about 60 feet high, rises through the coral in the south-eastern part of the island. The original structure of the trachyte is still discernible; but the alkaline silicates have been replaced by phosphates of calcium, aluminium, and iron. The main portion of the deposit on this island is, however, of a type similar to that found on the other islands.

On most of the islands the underlying coral shows signs of partial dolomitization (43 to 45 per cent. of magnesium carbonate), the magnesia being chiefly derived from the guano.

It is not my purpose to attempt to consider the numerous and complicated chemical reactions which may certainly, probably, or possibly occur when the complex solution, derived from the guano by the action of meteoric waters, interacts with the underlying rock. Here it will be sufficient to consider the solution as containing, in its first phase, calcium phosphate, ammonium phosphate, and free phosphoric acid; and in its second phase as containing tricalcium phosphate as a major constituent.

The products formed by the interaction of this solution of guano on the underlying coral mass are similar in all the deposits; but the ultimate results of the reactions are so completely exhibited in the Ocean Island deposit that I propose to deal with them when making detailed reference to that island.

II. Bibliography.

The literature having reference to the phosphate deposits of the South Seas is very scanty, and few publications exist which deal with anything more than a superficial examination of the deposits. The list given below may be taken as practically complete:—

(1) 'The Guano & other Phosphatic Deposits occurring on Malden Island.' W. A. Dixon, Journn. Roy. Soc. N.S.W. vol. xi (1877) p. 176.

This is, so far as I am aware, the first serious attempt to observe

[1] W. J. Wharton, Q. J. G. S. vol. liv (1898) p. 228.

methodically the conditions under which the phosphate deposits of the Pacific were formed. The author records several interesting observations. At the time when his paper was written, Ocean Island, as a phosphate deposit, was unknown.

(2) 'Nature & Origin of Deposits of Phosphate of Lime.' R. A. F. Penrose, Jr., Bull. U.S. Geol. Surv. No. 46, vol. vii (1888) p. 475.

This paper includes a comprehensive account of the then known phosphate deposits of the world. At the time when it was written, the most valuable of the Pacific phosphate deposits had not been discovered.

(3) 'Phosphate-Deposits of Ocean & Pleasant Islands.' F. Danvers Power, Trans. Austral. Inst. Min. Eng. vol. x (1905) p. 213.

Taking into consideration the short time that this author spent on these islands, his account is remarkably comprehensive and accurate. The paper is illustrated by plans and several good photographs, and is a valuable contribution to the subject. With the facts recorded by this author, I am in almost entire agreement; but with his theory of the mode of formation of the present deposit from the original guano I am in almost entire disagreement.

(4) 'Corallogene Phosphat-Inseln Austral-Oceaniens & ihre Produkte.' Carl Elschner, Lübeck, 1913.

In this book the author has collected data and photographs from various sources, and he is particularly indebted to Mr. Danvers Power's paper. There is little original matter of any value in the book, and very little discrimination has been used in the selection of data. The most valuable part of this work lies in the illustrations, some of which are beautifully reproduced.

III. General Structure of Ocean Island.

Ocean Island, as it exists at the present day, consists of a mass of dolomitized coral, almost completely covered by a cap of calcium phosphate, and shaped like a flat dome. It rises at its highest point to 300 feet above sea-level. The circumference of the island is about 6 miles, the coast-line being almost circular, with the exception of the bight known as Home Bay on the south-west. The latitude and longitude of the island have been variously given, the extreme figures differing as much as 14′, but lat. 0° 52′ S. and long. 169° 32′ E. may be taken as very nearly correct, as I have obtained confirmation of these figures from many able navigators who visited the island.

In all but the southernmost portion, the coast consists of nearly vertical and much eroded cliffs up to 30 feet in height, and seaward extends a platform of marine erosion averaging about 100 yards in width.

As stated above, practically the whole of the island is capped by a deposit of phosphate, sometimes as much as 80 feet thick, but

usually less than 50 feet. This covering is known to be lacking only where a thin line of raised beach occurs at the extreme north of the island; but at the extreme southern point the phosphate, although there is little doubt of its occurrence, is masked by a modern beach-formation. The topography of the coral basis of the island is almost entirely hidden by the capping of phosphate; but there is sufficient evidence available, particularly now that part of the phosphate has been removed, to form some idea of the shape of the underlying mass. This appears to consist of a number of roughly circular platforms bounded towards the sea by almost vertical cliffs, a section of the coral below the phosphate displaying a series of steps. These platforms have been much affected by subaërial erosion (prior to the deposition of the guano), and by the solutions leached from the guano; but at least three of them can be traced round the island, and it is found that they dip at an angle of rather less than a third of a degree south-south-eastwards.

Outside these tilted platforms occurs an almost horizontal platform covered with recent beach-material, and beyond this again is the platform of marine erosion at sea-level to which reference has already been made. At the present time this platform is being extended inland by the sea.[1]

IV. The Capping of Phosphate.

Mr. Danvers Power divides the capping of phosphate in Ocean Island into two main types: 'alluvial' phosphate and 'rock' phosphate. Both of these terms I consider misleading, since the 'alluvial' phosphate has no connexion with alluvial deposits as the term is understood by geologists, and the word 'rock' is used in too limited a sense. I propose, therefore, to replace these terms by using 'incoherent phosphate rock' for what has been known as 'alluvial' phosphate, and 'coherent phosphate rock' for 'rock' phosphate.

Considering the Ocean Island deposit as a whole, rather more than half is made up of incoherent phosphate, and rather less than half of coherent phosphate.

Incoherent phosphate consists of 'pebbles,' sometimes subangular and measuring 2 inches or more in diameter, together with smaller 'fragments' and pisolitic and oolitic grains grading down to dust. When wet it forms, in most grades, a clay-like material in which the larger 'pebbles' are embedded. In colour it varies, according to the percentage of contained tricalcium phosphate, from leather-brown in the lower grades to pale buff in the highest

[1] That the reef at present surrounding the island is a plane of marine denudation, cut out of an older reef, is shown by the fact that stumps of denuded pinnacles can be observed on the present surface. To-day this marine plane is being extended inland, the honeycombed coral of the land-mass as it is encroached upon by the sea being filled in with calcium carbonate, both by simple precipitation and by the agency of algæ.

grade, the former consisting very largely of pisolitic and oolitic grains, and the latter being more clay-like.

The fine material of the incoherent phosphate is derived partly from the insoluble residue of the original guano, and partly from the product of the rapid interaction of the solutions leached from the guano with the directly underlying coral-sand. The coarser material is the product of the slower action of replacement of calcium carbonate by tricalcium phosphate. This is accomplished by solutions, derived from the guano, which have lost their power of violently attacking coral by passage through the upper layers of the coral-sand.

The internal structure of the 'pebbles,' to which reference has been made above, proves them to be concretions. They are built up, like agate, of a series of concentric laminæ, the outermost one being the surface of the 'pebble,' and they imitate exactly the limestone concretions from which they are immediately derived, except for a slight difference in colour and for the fact that their main constituent is tricalcium phosphate.

Coherent phosphate is, in the main, almost identical in chemical composition with the incoherent phosphate. When any area is considered, however, the coherent phosphate is found to contain slightly less phosphate than the surrounding incoherent material. The coherent phosphate may be divided into three classes:—(*a*) fragmental; (*b*) phosphatized coral *in situ*; and (*c*) subvitreous phosphate.

(*a*) The fragmental phosphate may be coarse or fine in grain, grading imperceptibly into the incoherent variety. It occurs distributed in an irregular manner throughout the beds of incoherent phosphate. In external features and internal structure it imitates the various detrital limestones which are formed on a coral reef. Where it is laminated, the laminæ are but rarely horizontal; and every fact that I have observed in regard to this phosphate tends to prove its direct derivation from detrital coral-rock, or in rare cases by the secondary cementation of incoherent phosphate, the cementing material being, in this case, either subvitreous phosphate or phosphate precipitated from solution in a state of fine division. It may be stated, indeed, that the morphological characters of the phosphates generally are almost entirely derived from those of the pre-existing coral reef, and that all the typical forms in which reef-limestones occur find their counterpart in the phosphate deposit.

(*b*) Phosphatized coral *in situ*.—The coral platform, upon which the other types of phosphate deposit rest, consists of closely-packed masses of pinnacles (Karrenfeld), often 30 to 50 feet high. There is little doubt that these pinnacles owe their form, primarily, to subaërial denudation which occurred before the phosphate was deposited. The solutions leached from the guano have, however, considerably modified their form, rounding their outlines and, in some cases, converting them partly or wholly into a compact mass of phosphate.

(*c*) The translucent (subvitreous) variety of phosphate occurs sometimes in finely laminated masses, sometimes as a cementing ingredient, and often as an outside coating to phosphatized coral or as a lining to cavities within the unphosphatized coral. Its habitat, chemical composition, and structure all point to its rapid deposition from solution. As proof thereof may be cited the fact that this material occurs always in thin laminæ, the composition of which often exhibits a marked difference from that of the contiguous material, and contains a much smaller percentage of minor constituents than the other varieties. Specimens of translucent phosphate have been found in which the bubbles given off by the solution on evaporation have been perfectly preserved: in one case, the whole of the surface of a specimen consisted of the cast of unbroken bubbles, the escape of which had been prevented by a skin of phosphate formed on the surface of the solution. Under the microscope translucent phosphate is completely isotropic, and it is highly probable that the substance is in a colloidal form.

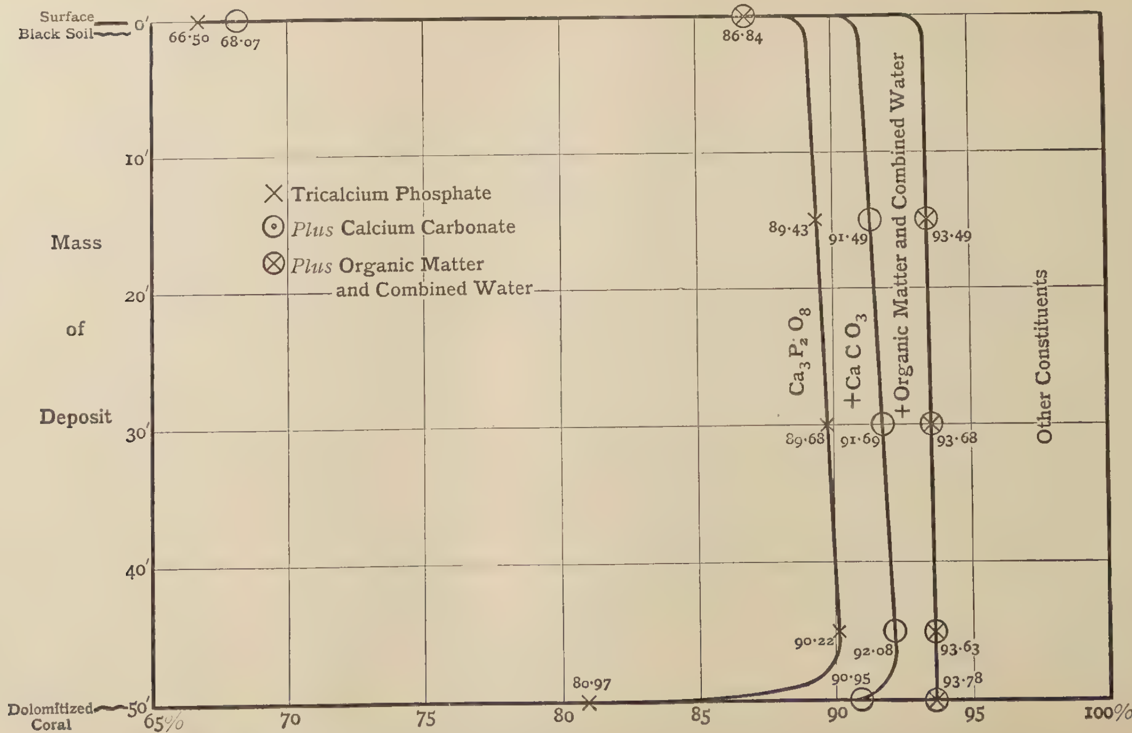
This translucent phosphate may be regarded as the ultimate product of the solutions leached from the guano. At the point where it is formed the mother-solution had no further action on coral, but consisted principally of an equilibrium mixture of calcium, hydrogen, phosphoric acid, and carbon dioxide ions and their corresponding salts. Loss of carbon dioxide caused a disturbance of this equilibrium, and tricalcium phosphate, together with a small amount of calcium carbonate, was deposited, constituting the translucent form.

V. Distribution within the Phosphate Deposit.

During my three years' residence on Ocean Island, I made a very extensive series of analyses from the soil, the natural surface of the phosphate deposit, and the deposit as exposed in excavations made either for the purpose of working or test. Many of the samples were taken from areas completely outside the then recognized phosphate 'fields,' and in the worked areas the deposit was tested by means of samples, taken at short distances apart, from the surface of the deposit to its total depth.

For the first few inches the deposit is black: this, in fact, constitutes the soil of the island. The tricalcium phosphate content of this soil is often more than 20 per cent. lower than the average for the area; its calcium carbonate percentage is below the average also, while its organic content is correspondingly high. The total lime percentage is but slightly below the average for the field, proving that the organic matter is present largely as calcium salts, the phosphoric acid having been released to act on the underlying material. In the excavations the black soil merges quickly (though imperceptibly) into the main mass of phosphate, and, when this is reached, the tricalcium phosphate content remains almost constant as one descends to a point within a few

Fig. 1.—*Curve showing characteristic variation in the composition of Ocean Island phosphate with the depth, from the surface of the deposit to its junction with the dolomitized coral.*



[The actual analyses for this graph were made on material obtained from a point near the centre of the island. The variation exhibits the same characteristics throughout the deposit.]

inches of the coral bottom. Here a rapid increase in the percentage of calcium carbonate occurs, together with a corresponding decrease in the percentage of tricalcium phosphate. The organic matter may either increase, remain constant, or decrease to a small extent. The lime percentage remains sensibly constant, with the exception of a small increase in the first few inches down from the surface. The changes cited above are illustrated by the accompanying graph (fig. 1, p. 7).

The coral lying directly below the deposit is almost completely dolomitized, containing usually from 43 to 45 per cent. of magnesium carbonate.

The foregoing remarks deal with the variation of the composition of the phosphate from surface to bottom at any one point.

The variation in composition of the phosphate from point to point, on the surface of the island, has yet to be considered, and this variation may be summarized, from the results of many hundreds of analyses, as follows:—

(1) Analyses show that, throughout the deposit itself (apart from the black soil) the extreme variation in phosphatic content in different parts of the island is between 79 and 92 per cent. of tricalcium phosphate.

(2) The variation in composition with depth rarely amounts to more than 1 per cent. in the body of the deposit at any one locality; it is sufficient, therefore, when considering the variation from point to point on the island, to take the average composition from surface to bottom at a single spot.

(3) In general, on proceeding from any place on the coast towards the centre of the island, the phosphate content of the deposit increases, while at the same time the deposit itself increases in thickness.

In detail, however, the distribution of the phosphate according to the content of tricalcium phosphate is found to follow a law which is elucidated by the co-ordination of the analyses.

(4) If we plot the results of the analyses in the form of 'isophosphatic lines,' these lines are found to cut the surface-contours of the ground in a perfectly regular fashion. These lines may be regarded as the outcrop of what can be called 'isophosphatic planes' in the deposit, and the excavations (up to the end of 1914) show that such planes are persistent throughout the whole of the phosphatic capping of the island, so far as it had been explored either in workings or in pits made for the purpose of test. These planes are not sharply marked off one from the other, the phosphate content varying quite gradually from 79 to 92 per cent. They are, of course, only recognizable where they cut the phosphate deposit, and not where they cut the unaltered coral base.

(5) A convenient plane for reference is the isophosphatic plane of 80 per cent. of tricalcium phosphate, which cuts the sea-level about 1/4 mile north of the southernmost point of the island. The line of intersection of this plane with sea-level is orientated east-

north-east and west-south-west, and its position is indicated on the accompanying plan (fig. 2). The plane rises north-north-westwards at an angle of 0° 17′, and plunges below the sea south-south-eastwards at the same angle.

(6) Analyses of samples taken in excavations show that the percentage of tricalcium phosphate in the deposit increases steadily with height above this datum-plane until a maximum of 92 per cent. is reached, at a point which, though not the highest point of the island, is the one farthest from the datum-plane. The change in the phosphatic content of the deposit as one approaches or

Fig. 2.—*Sketch-map of Ocean Island.*

recedes from the datum-plane is quite regular; in fact, it may be stated that the percentage of tricalcium phosphate at any point of the deposit is a straight-line function of the distance of that point from the datum-plane.

(7) Below the datum-plane the phosphate content falls at the same rate as above, to about 79 per cent. Lower than this, no phosphate deposits of any extent have been found, either the coast being reached or the deposit petering out and being replaced by unphosphatized coral-rock or coral-débris.

(8) The existence of this law of distribution makes it possible to predict with considerable accuracy the quality of phosphate to be expected in new areas of the island, to form an approximate

estimate of the productiveness of any area, and, within certain limits, to forecast the colour, specific gravity, vesicularity, factor of saturation by water, texture, and percentage of minor constituents.

(9) The planes give the impression that, since their formation, they have been tilted on an east-north-east to west-south-west axis to the extent of 0° 17′. The effect of such a tilt would be to raise the north-north-western part of the island about 30 feet. It is this part that is girt by a raised beach which reaches a maximum of 30 feet above the present sea-level. Further, the inclination of the isophosphatic planes is equal and parallel to that of the platforms in the coral under the phosphate, to which reference has already been made.

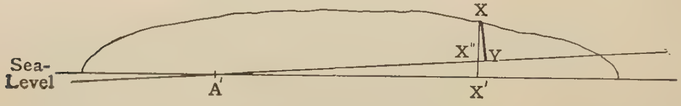
(10) The formula co-ordinating the analyses is expressed as follows:—

Percentage of $Ca_3P_2O_8$ at any point X
$=80+0{\cdot}04$ (height of X above sea-level in feet)
$-0{\cdot}04$ XA′ feet, tan 0° 17′,[1]

where AB is the line of intersection between the 80 per cent. datum-plane and sea-level, and XA′ is the horizontal distance of the point X from that line.

[1] This formula gives, for all bulk samples, a value closely approximating to that obtained by actual analysis, the difference usually being less than 0·2 per cent.: that is, within the experimental error of an analysis carried out under commercial conditions. The theoretical derivation of the formula is as follows:—Let the figure given below (fig. 3) represent a section of the island

Fig. 3.



cut by a plane at right angles to sea-level and the 80 per cent. datum-plane. A′ is the point of intersection of the trace of the datum-plane with sea-level, X is the point at which it is required to determine the percentage of tricalcium phosphate, XX′A′ and XYA′ are right angles.

It is assumed that the percentage of tricalcium phosphate is a function of the distance of X from the datum-plane, and the formula will therefore be of the type:—$Ca_3P_2O_8$ per cent.$=80+(f)$XY.

By analysis in the field it was found that $f=0{\cdot}04$ when XY is measured in feet. Hence $Ca_3P_2O_8$ per cent.$=80+0{\cdot}04$ (XY feet). Now, as X″XY is a very small angle (17′), XX″ may be taken as equal to XY, without introducing sensible error, therefore:—

$Ca_3P_2O_8$ per cent.$=80+0{\cdot}04$ (XX″ feet)
$=80+0{\cdot}04$ (XX′ feet$-$X″X′ feet)
$=80+0{\cdot}04$ (height of X above sea-level in feet$-$A′X′ tan YAX′).

VI. Method of Formation.

Mr. Danvers Power considers that the present deposits were formed, first of all, by the deposition of tricalcium phosphate in the cavities of the original coral. This form he named 'primary rock-phosphate.' The coral-rock, with its phosphate-filled cavities, was then comminuted by marine action. The carbonate of lime (being softer and more readily soluble than the phosphate) was washed away, and left the waterworn particles of phosphate behind. Such particles he termed 'primary alluvial,' and they correspond to what I term 'incoherent phosphate rock.' When this material is cemented by more phosphate, Mr. Danvers Power calls it 'secondary rock-phosphate.' To account for that which I term 'fragmentary phosphate,' he assumes a second submergence of the island and terms the material 'secondary alluvial phosphate.' His theory, although ingenious, is not in consonance with the information now available. Some of the divergences are stated here.

First, the dolomite, in the cavities of which Mr. Danvers Power's 'primary rock-phosphate' occurs, is much harder than the general mass of the phosphate. Even if it were not so, the complete absence of unphosphatized coral fragments within the deposit would be difficult to explain. Secondly, the theory in no way explains the observed uniform variation in the percentage of tricalcium phosphate, according to the position of the sample taken. Thirdly, on the southern coast, where the phosphate reaches sea-level, the very action which Mr. Power regards as having produced a material containing 80 per cent. and more of tricalcium phosphate is in actual operation at the present day, and the result is a coral-sand containing usually less than 5 per cent. of tricalcium phosphate. Lastly, what Mr. Power considers to be waterworn grains are really pisolitic and oolitic particles, exhibiting, under the microscope, an internal banded structure, the bands being conformable with the outlines of the grain.

My theory is that the guano was deposited on a rising mass of coral, which had already suffered marine peneplanation, and had been considerably eroded during previous periods of the history of the island. As the island rose, the area on which the guano could be deposited was, naturally, extended radially. Thus the guano deposit would tend to be thick in the central parts of the island, and thin near the coast. This explains the greater thickness and the higher quality of the phosphate in the central parts of the island as known at the present day, the higher percentage of tricalcium phosphate being explained, of course, by the fact that the solutions leached from the guano not only had a longer period to act on the underlying coral of the central portions of the island, but that they were concentrated by passing through a greater thickness of guano before they reached the coral.

The uniformity in the variation of the percentage of tricalcium phosphate throughout the deposit points both to a uniform rate of

deposition of the guano and, contemporaneously, to a practically uninterrupted elevation. The deposition of guano, at least to any considerable extent, appears to have ceased before the final gentle tilting of the island occurred.

The solutions from the guano would, first of all, react vigorously with the coral and coral-sand directly beneath, the reaction resulting in a structureless mass of impure tricalcium phosphate. Following on the first violent action would be a slower replacement of calcium carbonate, in the underlying material, by tricalcium phosphate. Where the action occurred in connexion with the oolitic calcium carbonate so common on coral reefs, it would give rise to oolitic phosphate-particles, and form those types of phosphate which imitate various detrital and concretionary limestones. The coral not eaten away by the guano solutions would be changed by metasomatism into the phosphate pinnacles observed in the workings. Finally, the solutions would consist of an equilibrium mixture of tricalcium phosphate, calcium carbonate, and carbon dioxide bereft of the power to attack coral. By the loss of its carbon dioxide this solution would yield the substance to which reference has been made under the name of translucent phosphate.

The form of the coral pinnacles underlying the phosphate, and that of the concretionary limestone (now changed to phosphate) occurring between the pinnacles, suggest that the island suffered at least one submergence before the deposition of the guano, in any quantity, commenced. This supposition is strengthened by the fact that newer corals (now phosphatized) are occasionally found attached to the dolomitized pinnacles.

The island shows no evidence of having suffered any extensive submergence since the deposition of the guano. If submergence had occurred, there would certainly have been left traces of coral beaches overlying the phosphate deposit. No such beaches have been observed. It may be argued that such beaches were converted into phosphate by solutions leached from guano subsequently deposited. This may have happened, but I consider it very improbable, as I have shown that the variation in the percentage of tricalcium phosphate, within the deposit proper, rarely exceeds 1 from top to bottom at any point. If fossil beaches existed within the body of the deposit, there can be little doubt that they would be indicated by a local change in the phosphate content.

Since the cessation of the deposition of guano, the island shows evidence of having been tilted from the north-north-west towards the south-south-east, as recorded by the dips of the platforms of coral and by the isophosphatic planes.

Many hundreds of analyses have been reviewed in arriving at these conclusions. These show that in bulk samples, the percentage of tricalcium phosphate varies between 80 and 90. One representative analysis of the phosphate, when dried at 100° C., is recorded here :—

	Per cent.
$Ca_3P_2O_8$	87·5
$CaCO_3$	3·5
Organic matter	2·5
CaO combined with the above	1·0
CaF_2	3·0
Al_2O_3, Fe_2O_3	0·7
MgO	0·3
$CaSO_4$	0·5
SiO_2	1·0
Total	100·0

In general, the tricalcium phosphate, calcium carbonate, and organic matter make up about 93·5 per cent. of the material (whatever its grade), the other components showing but little variation, except in the subvitreous varieties which contain a smaller percentage of impurities.

The excess of lime shown in the analyses has given much trouble to Dr. Carl Elschner, who has invented various compounds to account for it. There is, however, no reasonable doubt that it is simply combined with the organic matter. Elschner states, without bringing forward any evidence, that the calcium fluoride is combined as apatite. The physical and chemical properties of the phosphate render it unlikely that such a resistant substance as apatite is present in any quantity, and it is my opinion that the fluorine occurs combined chiefly as silico-fluoride.

Mr. Danvers Power believes that the central portion of the deposit occupies the site of an old lagoon; but, so far as they have been revealed, the contours of the underlying coral-mass do not lend themselves to this view. The highest point of the island is, in fact, an outstanding and completely phosphatized coral-pinnacle, the roots of which extend, at a small depth from the surface, over a considerable area. I have every reason to believe that the flat top of the island represents the remains of an uppermost marine platform of coral.

VII. Conclusions.

(1) The base of Ocean Island consists of a typical fossil coral-reef, much altered by marine and subaërial denudation. Before the deposition of the guano occurred, this reef was partly dolomitized and suffered considerable erosion, the hollows in the eroded surface being afterwards filled in by detrital and oolitic limestones formed by marine action. The evidence available makes it probable that the reef has suffered more than one submergence and emergence previous to the deposition of the guano.

Practically all the fossil remains found in the deposit are so altered as to be indeterminable, the only specimen in good preservation being a single tooth of *Carcharodon megalodon*,[1] which would indicate that the age of the deposit is post-Miocene.

[1] *Teste* Dr. A. Morley Davies, *in litt.*

(2) The guano was deposited on a slowly rising reef, both deposition and emergence appearing to have been regular and without sensible break.

(3) The deposit, as it exists at the present day, consists of the insoluble parts of the original guano, together with detrital and oolitic limestones and the directly underlying coral-rock, all of which have been changed, by the metasomatic action of solutions leached from the guano, into a rock composed mainly of tricalcium phosphate and containing small percentages of calcium carbonate, calcium fluoride, and silica. This rock still bears the characteristic form of the original limestone.

(4) Subsequently to the deposition and leaching of the guano and the formation of the phosphate in its present form, the island has been tilted about a west-south-west and east-north-east axis towards the south-south-east, the axis being about 1/4 mile north of the southernmost point of the island (Sydney Point). This tilting occurred in comparatively recent times. After the tilting a slight elevation of the island, to the extent of about a couple of feet, is thought to have occurred, and this movement appears to be continuing at the present time.

(5) The study of the variation of the percentage of tricalcium phosphate throughout the deposit has brought to light its remarkable regularity, which may be represented by a series of *isophosphatic planes*. The direction of these planes confirms the gentle tilting suggested by geological evidence which, by itself, might have been overlooked or considered unsatisfactory. It is possible that a study, on the lines here suggested, of the other completely leached phosphate deposits occurring in the Pacific may help to elucidate the post-Tertiary movements of the Pacific floor; and it is with the object of stimulating such investigation that this paper has been written.

The work on which this paper is founded was done prior to the end of 1914, but up to the present I have had no opportunity of publishing the results achieved, first owing to the war, and secondly owing to absence abroad.

My sincere thanks are due to the Pacific Phosphate Company for permission to use results obtained while in their employ; to Prof. W. W. Watts, to whose untiring aid and helpful criticism the paper owes its present form, as also to other members of the staff of the Geological Department of the Imperial College of Science & Technology for much advice and help. The arduous work of preparing the paper for publication and of seeing it through the press has devolved on Mr. G. S. Sweeting, F.G.S., to whom my best thanks are due.

Discussion.

Mr. J. F. N. Green referred to the interest of the differential movement, proved, he thought, for the first time for one of the

smaller limestone islands of the Pacific. There might be significance in the occurrence of thick deposits of phosphate-rock in the Pacific on 'high islands' only, whereas 'low islands' supplied inferior surface-material, presumably owing to shorter occupation by birds. Perhaps a short time ago, geologically speaking, the low-lying islands were under water, which would also account for the late arrival of Man.

The AUTHOR replied that most of the terraced limestone-islands of the Pacific have been noted as approximating 100 metres (328 feet), and Ocean Island conforms to the general rule. Apparently, however, no evidence of slight tilting has been noted before. The reason that all the deposits of any great value occur on such islands may be due to the very uneven surface which a platform of eroded coral offers, the guano being thus trapped in a way that would be impossible on the smooth surface of the low-lying islands. The reasons for the disappearance of the birds are obscure; but it may be noted that the really extensive and older phosphate deposits of the Pacific tend to occur in the west, while the smaller and more recent deposits are found most frequently in the east.

2. *The* Igneous *and* Associated Rocks *of* Llanwrtyd (Brecon).

By Laurence Dudley Stamp, B.A., D.Sc., A.K.C.(Lond.), F.G.S., and Sidney William Wooldridge, B.Sc., F.G.S.

(Read November 9th, 1921.)

[Plates I & II.]

Contents.

Part I. Stratigraphical.

(1) Introduction.

North of the little town of Llanwrtyd Wells lies an oval patch of igneous rocks, about 3 miles long and half a mile broad. It has long been known that these rocks occupy the core of an anticline—that of the Vale of Towy—which strikes approximately north-north-east and south-south-west. Some years ago I visited the igneous rocks in the neighbourhood of Builth (described by Mr. Henry Woods in 1894). It has usually been presumed that the igneous rocks of Llanwrtyd, which locality is about 10 miles west-south-west of Builth, are of the same age as those near the latter town. Accordingly, in order to test the truth of this belief, a survey of the Llanwrtyd rocks was begun. It was found that the igneous rocks differed considerably from those near Builth, but at that time no palæontological evidence of their age was found. In 1920, while studying the Siluro-Devonian junction in Central Wales, I took the opportunity of revisiting Llanwrtyd Wells for the purpose of completing the mapping of the igneous rocks and Ordovician sediments. I was accompanied on this occasion by Mr. Wooldridge, who has undertaken the petrological description of the rocks.

(2) Previous Work.

The literature relating to this district is scanty. The only description is that given by Sir Roderick Murchison.[1] He states that the presence of mineral springs at Llanwrtyd Wells led him to suspect the presence of igneous rocks in the neighbourhood, and his investigations proved that such rocks did occur. His account occupies two pages in the 'Silurian System', and is accompanied by two woodcuts by Mrs. Traherne. Curiously enough, the description of the Llanwrtyd rocks is not repeated in 'Siluria', and the references in that work are very brief.[2]

The district was mapped by the Geological Survey on the 1-inch scale, and the map (Sheet 56 S.W.) was published in 1850. The structure is fairly accurately shown, but no attempt is made to distinguish between the breccias, ashes, lavas, and intrusions, all being coloured as 'Felspathic Trap.' The structure is further shown in Horizontal Sections 3 & 6.

Prof. W. G. Fearnsides[3] has stated that

'beds of Arenig age . . . . form the core of the Carneddau (Llandrindod-Builth) mass, and appear also at Llanwrtyd . . . .' [and] 'at Llanwrtyd the succession seems to begin with the tuning-fork graptolite-beds. In each area, as at Arenig, the volcanic series begins with basic andesites and through rhyolites passes to rhyolitic ashes before the oncoming of the Llandeilo Flag Series.'

These remarks may apply to the Llandrindod-Builth area, but they are certainly not true of the Llanwrtyd district. Other references to the district are of a general nature, and will be quoted, where necessary, in the sequel.

Murchison's general description is so clear that we may, with advantage, quote portions of it here. He writes:

'I found a line of intrusive rock, about three miles in length and half-a-mile in its greatest width, running, like the trap ridges of Radnorshire, from north-east to south-west. A narrow and deep dell, through which flows the rivulet Cerdin, divides this elliptical-shaped ridge into two mountains, Caer-cwm and Garn-dwad, each about 1600 feet in height. At the north-eastern extremity of Caer-cwm, trap is seen, for the last time, on the banks of the little stream Nant-einon, alternating in thin courses with slaty schists; whilst at the south-western end of Garn-dwad the trap crosses the Ithon between Llanwrtyd and the mineral spring, near a boss of rock called Gwern-goch, upon the right bank of that river, and near the farm-house of Dol-y-dymmor. In this ridge of Garn-dwad and Caer-cwm the predominant character of the trap is porphyritic, and the following varieties occur: . . . .' ('The Silurian System' 1839, *loc. supra cit.*)

[Murchison distinguishes seven varieties of 'trap'; of these No. 7 is the spilite ('amygdaloidal trap, cellular on the weathered surface'), 5 is the intrusive rock ('greenstone'), 4 is probably the massive form of spilite, the others are varieties of the ashes.]

'Whilst the porphyritic trap occasionally peeps out in rugged bosses along the summits and sides of the hill of Caer-cwm and Garn-dwad, the little transverse dell of the Cerdin lays bare the true nature of this nucleus in a rock called Craig-castell, which towers above the left bank of the stream. . . .'

1 'The Silurian System' vol. i (1839) pp. 343–46.

2 'Siluria' 4th ed. (1867) pp. 57–58.

3 'North & Central Wales' (Geology in the Field) Jubilee Vol. Geol. Assoc. (1910) pp. 796–97.

(3) The Succession of the Strata.

The succession may be tabulated generally thus :—

(7. Intrusion.)
6. Black Slates, cleaved and almost unfossiliferous.
5. The Upper Ashes { fossiliferous ashy shales. / fine banded ashes. / coarse ashes.
4. Hardened mudstones, with a band of ashy limestone (weathering to 'rottenstone') in the upper part.
3. The spilites and spilite-breccias.
2. Hardened sediments, with fossiliferous mudstones.
1. The Lower Ashes { coarse breccia (rhyolitic). / fairly coarse ashes.

Even in the short distance of 3 miles, from one end of the igneous mass to the other, the succession shows considerable variation. This is particularly the case with the ashes in their degree of coarseness, and with the spilites.

The whole series (except the higher parts of 6) may be described as of Glenkiln-Hartfell age, being on the same horizon as the *Dicranograptus* Shales of South Wales.

(*a*) The Lower Ashes and Breccias.

These beds are only seen in the deep transverse valley of the Nant Cerdin. The base is not visible, and the lowest strata seen—well exposed in the bed of the stream, at the point A marked on the map (Pl. II)—consist of compact, fairly coarse ashes. The rock is pale greenish-grey, and contains whitish angular fragments. Occasional darker veins, which are so arranged as to simulate the divisions between spilite-'pillows,' are also seen. A closer examination, however, reveals no lithological difference, beyond a slight deepening in colour of the matrix.

Succeeding the ashes is a coarse breccia, which forms rugged, almost vertical cliffs (the Craig Castell of Murchison), some 80 or 90 feet high, on the northern side of the stream. The rock has a remarkable and distinctive appearance, since the brecciated fragments weather white while the matrix remains black. The whole rock seems to have been silicified, and tends to break with an even or semi-conchoidal fracture. It is well jointed,[1] and the presence of east-and-west joints, together with a slight southward pitch, have produced the steep cliffs. Unweathered portions are of a uniform black or dark grey. The rock bears a close resemblance to certain rhyolitic flow-breccias described from other parts of Wales: as, for example, Conway.[2] On the other hand, features such as banding, observable in one fragment, cannot be traced in the next, and therefore the rock is not comparable with a shatter-breccia. On the whole, the Llanwrtyd breccia seems to agree closely with the flow-brecciated (or auto-brecciated) lavas described by Mr. J. F. N. Green from the Lake District.[3]

[1] Murchison states that the rock breaks up into slender four-sided columns.

[2] G. L. Elles, 'The Relation of the Ordovician & Silurian Rocks of Conway (North Wales)' Q. J. G. S. vol. lxv (1909) p. 169.

[3] 'The Vulcanicity of the Lake District' Proc. Geol. Assoc. vol. xxx (1919) p. 153.

(*b*) The Hardened Sediments.

The sediments which succeed the rhyolite-breccia are not well exposed. The principal section is in a tiny stream flowing into the Nant Cerdin (marked B on the map, Pl. II). Elsewhere the position of these beds is marked by grass-covered slopes. They appear to consist of hardened mudstones, with some gritty or ashy bands. The interest of these mudstones lies in the fact that they have afforded a fossiliferous horizon. At the point marked C on the map (Pl. II), situated in the higher part of the beds, and only a short distance below the horizon of the spilites, the hard black shales yielded a brachiopod and numerous graptolites. I am greatly indebted to Miss G. L. Elles, D.Sc., for the determination of the graptolites. The fauna, though a small one, is quite distinctive:—

Siphonotreta micula M'Coy.
Dicranograptus rectus Hopkinson.
Glyptograptus teretiusculus var. *siccatus* Elles & Wood.
Climacograptus schärenbergi Lapworth.
Amplexograptus perexcavatus Lapworth.

This association is characteristic of the *Dicranograptus* Shales—particularly of the horizon of the Mydrim Limestone of South Wales, and of the higher part of the Glenkiln Shale (Zone of *Dicranograptus rectus*) of Southern Scotland. The important point is that this graptolitic horizon occurs below the spilites: hence the latter must be younger. The significance of this fact will be considered in more detail later.

(*c*) The Spilites and Spilite-Breccias.

There are three main exposures of this horizon :—

(i) In the bed of the River Irfon and on the northern flank of its valley in the south.
(ii) On each side of the transverse valley of the Nant Cerdin.
(iii) In the central ridge of Car Cwm, on the north.

The spilites vary greatly in their thickness and appearance in the field. In places pillow-structure is well developed; at other points the rock is quite massive. In colour, they vary from a pale bluish-green to dark greenish-grey, the latter hue being characteristic of the massive spilite of Car Cwm. The rocks are nearly always vesicular, to a greater or less degree. The vesicles are filled, either with some pale mineral (particularly calcite), when they are comparatively inconspicuous; or with a dark-green chlorite having lustrous cleavage-planes, when the rock assumes a conspicuous spotted appearance. The material in the vesicles weathers easily, and the resulting rock has a spongy aspect. In the south, where they form the bold bluff overlooking the river, the spilites are fairly massive in the lower part; but they have a characteristic 'pillowy' structure in the upper part. Here some of the 'pillows' are of great size, ranging up to 10 or 15 feet in diameter. They generally have an extremely thin, almost glassy crust, followed by a very vesicular band 4 to 10 inches thick, the vesicles becoming fewer towards the centre. The central parts have

only a few large vesicles. The underlying beds are not exposed, and, owing to the strong southward pitch of the anticline, it is difficult to estimate the thickness of the spilites. They appear, however, to be certainly not less than 40 or 50 feet thick, and may be much more. Beautifully fresh examples of the rock—here of a pale greenish colour with inconspicuous vesicles—may be collected from the bed of the River Irfon. The spilite forms reefs crossing the river obliquely, and, when the water is low, the little bands of chert separating the 'pillows' are well seen.

As we pass to the transverse valley of the Nant Cerdin, the spilites may be traced almost continuously on both sides of the valley, and show at once the anticlinal structure of the mass. In the upper part of the band marked as spilite on the map (Pl. II), two flows, each a few feet thick, may sometimes be distinguished. Both consist, for the greater part, of typical pillow-lava; and the two are separated by a few feet of ashy sediments. The interest of this section, however, lies in the development below the spilite-flows of a curious rock which may be described as a 'spilite-breccia.' The term is not a new one, having been used before by Mr. C. I. Gardiner & Prof. S. H. Reynolds.[1] The rock consists of a typical breccia or coarse ash, in which are embedded innumerable 'bombs' of spilite. These 'bombs' resemble miniature pillows; they are vesicular within, and possess a thin glassy crust. They vary in size from about 1 to more than 12 inches in diameter. As the spilite-'bombs' increase in size and number, the rock becomes indistinguishable from an ordinary spilite-flow. When weathered, the rounded outlines of the spilite-'bombs' contrast strongly with the roughened angular appearance of the ashy matrix. This rock is not easily found *in situ*; but numerous blocks are scattered on the southern slopes of the Nant-Cerdin Valley, and have been built into the wall which crosses that valley from north to south (see map, Pl. II). Farther north, the crags marked D on the map exhibit other examples of spilite-breccia. It is interesting to note that a very similar rock has been described from Jersey:[2] there again the breccia passes gradually upwards into true lava-flows.

Equally curious is the rock which constitutes the core of the anticline on the north, forming the central ridge of Car Cwm. The main mass of the rock presents a distinctive appearance; it is dark greenish-grey, with numerous black specks about 1/8 inch in diameter. These specks represent vesicles infilled with a dark chloritic material. The base of this rock is not seen, and its relations with the overlying beds are not easily determined. It seems, however, to become more vesicular in the upper part, and to pass gradually upwards into typical pillow-lavas. There is thus a fringe of typical pillowy spilites and interbedded cherts surrounding the central mass, which I regard as the massive lower part of the spilite-flow.

[1] 'The Ordovician & Silurian Rocks of the Kilbride Peninsula (Mayo)' Q. J. G. S. vol. lxviii (1912) p. 75.

[2] T. G. Bonney & C. A. Raisin, 'On the so-called Spilites of Jersey' Geol. Mag. 1893, p. 59.

(*d*) The Hardened Mudstones, etc.

The spilites are succeeded by a somewhat variable group of sediments. The main part of the division seems to consist of hardened mudstones with several bands of flinty 'hornstone' and ashes. Murchison states that the

'schist . . . is silicified or in the state of hornstone, highly translucent at the edges, of a scaly fracture and dark-grey colour with cloudy streaks, as if formed by an imperfect separation of hornblende. Other varieties are black Lydian stones, ringing under the hammer, and splitting with a fine conchoidal fracture; some of them containing a number of bright metallic spots, probably of oxide of iron.' ('The Silurian System' vol. i, 1839, p. 344.)

The softer sediments are so rarely seen that one is apt to ignore their existence, especially as the bands of 'hornstone' and ash are often well exposed. On the north several such bands can be traced and mapped, but the arrangement is more irregular in the south. Hard grit-bands also occur, especially in the south. A feature of great interest is the occurrence, about 30 or 40 feet from the top of the group, of an ashy impure limestone, which weathers on the surface to a typical 'rotten-stone', such as one sees in the Llandeilian near Llandeilo. In the fresh rock it is practically impossible to distinguish any fossils; but in the weathered rock abundant traces of fragmentary brachiopods, crinoid-ossicles, and other remains are visible. The only determinations which have been at all possible include

Orthis elegantula (?) Dalman.	Cystid-plates.
Orthis vespertilio (?) J. de C. Sowerby.	Bryozoa.
Rafinesquina sp. (?).	

Exposures may be typically seen at the point marked E on the map (Pl. II), and blocks occur scattered over the surface in a variety of situations.

The graptolitic horizons which occur both below and above this group indicate an age equivalent to that of the Mydrim-Limestone division of the *Dicranograptus* Shales of South Wales. In this connexion the occurrence of a rottenstone so far north is interesting, as the whole horizon is a calcareous one in the south.

(*e*) The Upper Ashes.

Most of the hard bands in the succession form marked features, and this is especially true of the Upper Ashes. The lower part of the division consists in the south of a bed of coarse ash some 40 feet thick. On the west it dips away from the centre of the anticline at an angle of about 45°, and forms a conspicuous crag north of the River Irfon, about 300 yards south-east of Llanwrtyd Church. It can also be traced south of the river, as a tree-covered escarpment, which gradually becomes less conspicuous as the dip decreases and one approaches the centre of the strongly-pitching anticline. A considerable area of the summit and eastern slopes of the southern range of hills (Garn Dwad) consists of these ashes. Actually the slopes of the hill are largely the dip-slopes of the

lower beds of these Upper Ashes. Scattered about the summit and eastern slopes one sees numerous flat-topped crags, rising above the general slope like crumbling castles: these are remnants of the middle and upper beds of the Upper Ashes. Such masses may be seen at the points H & J marked on the map (Pl. II). The Upper Ashes (excluding the higher beds described below) consist for the greater part of coarse ashes, in places almost a breccia. They may be dark, but frequently are a dirty white: this seems to be due to agencies other than weathering. The coarse ashes are not well developed in the northern part of the area, and their place is taken by fine ashes or by 'hornstones.'

The coarse ashes pass upwards into a conspicuously-banded rock, which consists of fine ashy material. Occasionally one may find little bombs—an inch or so in diameter—which have dropped into the soft ashy bed, and caused a puckering of the otherwise even layers. This rock has been quarried in several places for local building-stone. It may be massive; but it is more often cleaved, and splits easily into slabs about half an inch thick.

In the upper part of these banded ashes—which are about 12 to 14 feet thick—bands of hard black shale occur. The latter have yielded fairly numerous graptolites, including the following:—

Dendroid graptolites.
Dicellograptus sextans Hall.
Dicellograptus sextans var. *exilis* Elles & Wood.
Glyptograptus teretiusculus var. *siccatus* Elles & Wood.

The graptolitic horizon may properly be regarded as occurring in the highest part of the Upper Ashes, for it is succeeded by a thin band of ashes, and then by the great mass of slates.

Although only one of the species just mentioned is found also at the lower fossiliferous horizon, the two faunas may be considered together, as the species occur in association and are characteristic of a single horizon elsewhere. The list from the two horizons: namely, just below the spilites and at the top of the Upper Ashes, includes the following species:—

Dicranograptus rectus Hopkinson.
Dicellograptus sextans Hall.
Dicellograptus sextans var. *exilis* Elles & Wood.
Climacograptus schärenbergi Lapworth.
Amplexograptus perexcavatus Lapworth.
Glyptograptus teretiusculus var. *siccatus* Elles & Wood.
Siphonotreta micula M'Coy.

Miss G. L. Elles remarks that this assemblage is characteristic of the higher part of the Glenkiln Shales of Scotland—the zone of *Dicranograptus rectus*. If one studies the faunas of the *Dicranograptus* Shales of South Wales, it is found that three divisions can be separated: the lower one of the Hendre Shales, the middle one of the Mydrim Limestone, and the upper one of the Mydrim Shales.[1] The officers of the Geological Survey enumerate twelve

[1] 'The Geology of the South Wales Coalfield, pt. xi: The Country around Haverfordwest' Mem. Geol. Surv. 1914, p. 37.

species as common or reaching their maximum degree of abundance in the Mydrim Limestone.[1] The Llanwrtyd fauna includes no less than five of these species. Moreover, only one of the Llanwrtyd species (*Amplexograptus perexcavatus*, of which but one specimen was discovered) is found at all commonly at any other horizon in South Wales. We are, therefore, led to the conclusion that the graptolitic horizons are homotaxial with the Mydrim Limestone. This conclusion is further borne out, as we have mentioned above, by the occurrence of ashy limestones. Since the spilites and the Upper Ashes occur between the two graptolitic horizons, it follows that they are of the age of the Mydrim Limestone; while the Lower Ashes, if not of the same age, cannot be much earlier.

For the sake of convenience, the Geological Survey memoir has included the Mydrim Limestone and the Mydrim Shales in the Bala (Caradocian); but the remark is made therein that the true junction between the Llandeilian (Glenkiln) and the Caradocian (Hartfell) should be drawn somewhere in the Mydrim Shales.[2] Prof. W. W. Watts draws the boundary between the Mydrim Limestone and the Mydrim Shales, including the former in the Llandeilian.[3] According to the Geological Survey classification, the Llanwrtyd igneous rocks come at the base of the Caradocian; according to Prof. Watts's classification, at the top of the Llandeilian; and according to Miss Elles's classification,[4] towards the upper part of the Llandeilian (Glenkiln).

(*f*) The Black Slates.

The Upper Ashes are succeeded by a huge thickness of monotonous dark slates, much contorted and cleaved. These beds form the hills all round the igneous mass. A considerable search has resulted only in the discovery of indeterminable fragments of graptolites of Diplograptid type. Some grit-bands occur in the slates at certain horizons.

(*g*) The Intrusion.

The main anticline is bounded on the western side by a great fault, which must have a downthrow to the west, since it cuts off part of the Upper Ashes. Along the line of this fault, and apparently on its western side, there is a curious intrusion. Unfortunately, it has not been possible to determine the exact field relationships of this rock; it may be intruded into the Black Slates at an unknown distance above the Upper Ashes, or it may

[1] Mem. Geol. Surv. 1914, pp. 38–39.
[2] 'The Geology of the South Wales Coalfield, pt. x: The Country around Carmarthen' Mem. Geol. Surv. 1909, p. 46.
[3] 'Handbuch der Regionalen Geologie, vol. iii, pt. 1: The British Isles' 1917, pp. 72–73.
[4] 'The Relation of the Ordovician & Silurian Rocks of Conway (North Wales)' Q. J. G. S. vol. lxv (1909) p. 169.

be intruded along the fault itself. There seems to be only one small piece of evidence that bears on this question: the faulting has been accompanied by a considerable amount of shattering and subsequent infilling of the cracks by quartz. In fact, some of the 'hornstones' near the fault are riddled with small quartz-veins. Now, the intrusion is also affected by this quartz-veining to some extent: consequently, if it was intruded along the fault, it was afterwards subjected to shattering and quartz-veining due to renewed movement along the fault-line. In the field the intrusion has a curious patchy appearance on a small scale, and also exhibits a rough flow-structure. This appearance led me to name the rock 'mixture-rock' in the field; but its hybrid nature has not been borne out by detailed examination. The intrusion is seen in some crags about 100 yards south-east of Pen-y-banc Farm; it is the 'greenstone' of Murchison.

As our main object in this investigation was to determine the horizon of the volcanic rocks, the upper slates and shales were not examined in detail; but one further point may be mentioned. There are shown on the 1-inch Geological Survey map two narrow outcrops of 'felspathic trap,' occurring about a mile west of the main mass and striking in the same direction. These were visited by one of us (S. W. W.), who found that they were in reality quartzose conglomerates absolutely unlike anything seen in the main mass. Possibly the occurrence of white specks of quartz caused these to be confused with the Upper Ashes, which sometimes show white specks due to angular fragments of felspar or rhyolite. There seem to be several bands of conglomerate; judging by surface-features, the principal one extends both north-north-eastwards and south-south-westwards. It must occupy a position many hundreds, or perhaps thousands, of feet above the Upper Ashes.

There is a little evidence for considering this main conglomerate as the base of the Valentian. It agrees in character with the Cerig-Gwynion Grit of Rhayader[1] on the north-north-east, and with the Shon-Nicholas Conglomerate and Pen-y-ddinas Grit at Llansawel on the south-west. The two last-named grits have already been correlated with the Cerig-Gwynion Grit by Miss H. Drew & Miss I. L. Slater.[2] The outcrop of the grit west of Llanwrtyd, if prolonged, would pass into that of the Cerig-Gwynion Grit of Rhayader and of the grits of the Llansawel district, and surface-features tend to show that such a prolongation does actually occur.

[1] H. Lapworth, 'The Silurian Sequence of Rhayader' Q. J. G. S. vol. lvi (1900) p. 95.

[2] 'Notes on the Geology of the District around Llansawel (Carmarthenshire)' *Ibid.* vol. lxvi (1910) p. 402.

(4) Description of Typical Sections.

By far the most important and complete section is seen on each side of the deep valley of the Nant Cerdin, which cuts right across the anticline about a mile and a half north of Llanwrtyd Wells. Owing to the pronounced pitch of the anticline—or rather dome—at its northern and southern ends, the other two streams which cut across the anticline only expose the higher beds. The streams are respectively the River Irfon on the south (where the main anticline has a strong southward pitch), and the Nant Cwm-du on the north (where the northward pitch is equally well marked).

(*a*) The Valley of the Nant Cerdin.

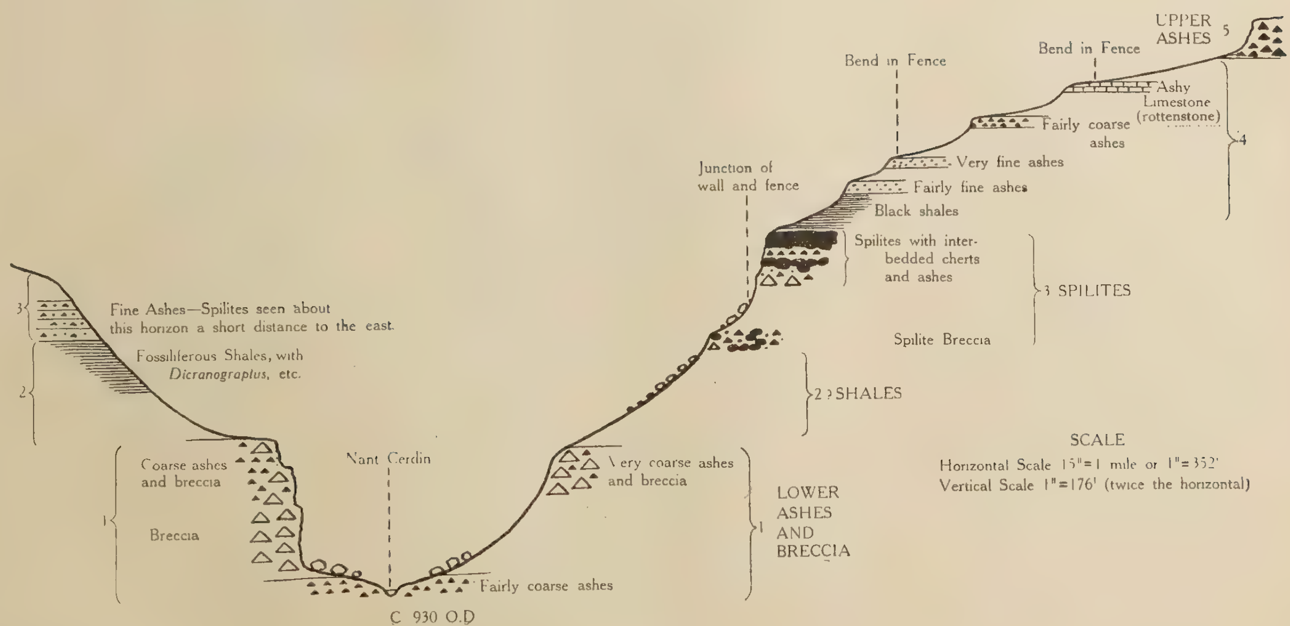
As mentioned above, it is only in the deep valley of the Nant Cerdin that some of the lower beds of the Llanwrtyd sequence are exposed. The transverse section of the anticline (fig. 3, p. 30) is taken a short distance south of, and parallel to, the valley, and one may regard the section as a diagrammatic view of the arrangement of the beds on the southern slope of the valley. The sequence of rocks in the centre of the anticline is shown in greater detail in fig. 1 (p. 26). A fence[1] runs across the valley from north to south, coinciding almost exactly with the axis of the fold, and the section has been taken very nearly along this line. On the north of the stream the exposures occur in a little gully a few yards east of the fence, and it is here that one sees the dark graptolitic shales yielding *Dicranograptus*, etc. On the southern side the exposures are generally a few yards west of the fence. On each side of the valley, but particularly on the southern flank, the various hard bands form sparsely covered features, while the intervening shales are grass-covered slopes. When standing on the opposite slope of the valley, one is able easily to distinguish the anticlinal structure by means of these hard bands. The detailed section is as follows:—

		Approximate thickness in feet.
5. Upper Ashes ...	Coarse rhyolitic ash, frequently whitish by alteration or weathering, forming isolated tumps or crags near the crest of the hill.	40
4. Hardened Mudstones, etc.	Not exposed, presumably shales. Band of ashy limestone. Not exposed, presumably shales. Band of fairly coarse ashes. Not exposed, presumably shales. Band of very fine ashes. Shales (20 feet). Band of very fine ashes. Black Shales (50 feet).	160

[1] A wall on the lower ground

Fig. 1.

Section across the Nant Cerdin Valley from North to South.



		Approximate thickness in feet.
3. Spilites	Spilites showing typical pillow-structure, with associated cherts and ashes. The latter are frequently quite coarse, but are intimately associated with the lava. One can distinguish two flows in the upper part, separated by a few feet of ash. Spilite-breccia (see above, p. 20). The beds exposed in the gully on the north at this horizon seem to be mostly ashes, but the spilite-flows are seen both on the east and on the west—only about 150 yards in each case.	100
2. Shales............	Not exposed on the southern side. On the north they consist of hard, black, uncleaved mudstones with fossils in the upper part (*Dicranograptus*).	90
1. Lower Ashes and Breccia.	Coarse ashes and breccia, passing down into a coarse breccia of rhyolitic appearance. These form almost vertical cliffs on the northern side of the valley.	110
	Fairly coarse ashes, with white fragments of felspar in a greenish matrix ...... seen for	15
	Total............	515

(*b*) The Valley of the River Irfon (northern side).

The section across the anticline shown in fig. 2 (p. 30) is taken a short distance north of the valley of the Irfon, and represents fairly closely a view of the rocks exposed on the northern flank of the valley itself. The spilites are the lowest beds seen, and form a somewhat rugged cliff overlooking the river. The lower part consists of very large 'pillows'—some measure more than 15 feet in diameter; while the pillows in the upper part are smaller, and more normal in size. The sediments which succeed the spilites are not clearly exposed, but seem to consist almost entirely of hard banded grits, tough blocky mudstones, and indurated shales. Some 40 feet below the summit a band of ashy limestone (or, when weathered, 'rottenstone') is found. It crops out in a tiny crag on the west side of the hill, about 20 yards from the conspicuous crags made by the Upper Ashes. The latter are well exposed, and here dip at a high angle westwards. The succeeding banded ashes are better seen on the eastern side of the hill. They are exposed in the quarry marked on the map (Pl. II), where one finds the hardened graptolitic shale yielding *Dicellograptus*, etc., in the upper part.

(*c*) The Valley of the Nant Cwm-du.

The rocks specified below are exposed in the bed of the stream, and are also seen pitching northwards on the hill-slope to the south:—

Upper Ashes	Fairly coarse ashes.
	Fine 'hornstone.'

Hardened Mudstones ...	Shales. Ashy limestone. Fairly coarse ashes. 'Hornstone.' Shales. Fairly fine ashes.

This section is of especial interest, since it exposes the shales between the hard bands of ash and 'hornstone.' In this way it fills in the gaps in the first section. It is to be noted that fine 'hornstone' partly replaces the coarse beds of the Upper Ashes. The jointing of the rocks is well seen in the bed of the stream.

(*d*) Quarry west of Nant-Gwyn Farm (east side of the anticline).

Upper Ashes ...	Band of coarse ash..................	seen for 3 feet.
	Fine banded ash, well cleaved	12 feet.
	Bedded ash, with large fragments	2 feet.
	Coarse ash	seen for 6 feet.

The puckering (in some cases due to the presence of a little volcanic bomb) in the bedding-planes of the banded ash is interesting and well shown.

(5) Structure and Scenery of the District.

The structure and the scenery of the Llanwrtyd area are so closely connected that it seems advantageous to consider them together. Speaking broadly, there is an important anticline running from north-north-east to south-south-west in Central Wales, known by the name of the Towy Anticline.[1] Its axis passes from the neighbourhood of Carmarthen eastwards along the Vale of Towy to near Llandovery; thence it passes in a more northerly direction through the Sugar Loaf to Llanwrtyd and to the east of Rhayader. It is this anticline which brings up the igneous rocks of Llanwrtyd.

The igneous rocks have proved more resistant to weathering than the overlying slates, and hence occupy an elevated ridge rising to over 1600 feet. The surface of this ridge, especially in the southern part, is roughly the dip-slope of the Upper Ashes. The covering of the Upper Ashes has, however, been pierced by the agents of denudation, and slightly older beds are exposed in places. In some cases, as mentioned above, isolated remnants of the Upper Ashes have been left, and present a very curious appearance. Murchison says that

> 'the upper parts and summits of these hills exhibit numberless rugged and irregular bosses of trap, sometimes carrying up fragments of altered or indurated schist . . . . .' ('The Silurian System' vol. i, 1839, p. 344.)

The core of the northern part of the range (known as Car Cwm) consists of the spilites.

[1] O. T. Jones, 'The Geological Structure of Central Wales & the Adjoining Regions' Q. J. G. S. vol. lxviii (1912) p. 328.

The area of igneous rocks is bounded on the west by a great fault. The direction of the fault is not quite parallel to the axis of the fold, wherefore in the north it cuts off a considerable part of the western limb of the fold: this is readily apparent from the map (Pl. II). The course of the fault is well marked topographically. In the south it occupies a deep, narrow, straight valley in the northern slope of the hill known as Banc Glyn Gyrnant. It skirts the eastern side of the valley of the Irfon near Llanwrtyd, and probably determines the direction of the river at this point. Near the intrusive mass it crosses higher ground (by Pen-y-banc Farm), but on the north again gives rise to a deep gully north-east of Pen-y-banc. The contorted rocks in this gully are described and figured in 'The Silurian System' (p. 344 & figs. 62, 64). Farther north it gives rise to the little rift-valley (Nant-y-Glo) north-east of Nant-yr-odyn Farm (seen in the distance in fig. 64 of 'The Silurian System').

The anticline of Llanwrtyd is, however, complicated by a series of folds which cross it almost at right angles, and cause a pronounced pitch in the north and south. More correctly, therefore, the igneous rocks are arranged in an elongated dome. The surface of the ground in the north follows the northward pitch in such wise that the ridge of Car Cwm sinks rapidly from 1600 to about 900 feet. At the southern end of the ridge the southward pitch is even more marked. The outcrop of the Upper Ashes drops from a level of 1300 feet at this point to about 800 (near the Well Bath-Houses) in a distance of less than half a mile. It is possible that this pitch is more apparent than real, as one must bear in mind the possible existence of an east-and-west fault in the valley of the Irfon immediately west of Llanwrtyd Wells. Some transverse faults from west-north-west to east-south-east certainly do occur in the district; but they are of small throw, as shown on the map (Pl. II). Some minor folding and faulting north of the transverse valley of the Nant Cerdin has given rise to a subsidiary dome-like structure east of Nant-yr-odyn Farm.

One of the most striking features of the district is undoubtedly the deep valley of the Nant Cerdin, which cuts the range in two. The origin of this valley is not readily apparent. It does not seem to be determined by a line of faulting; it is more probable that the Cerdin stream was deflected from its north-and-south course by the resistant intrusive mass on the south.

The close relationship between the present contours and the folding of the strata will be at once seen from the sections (figs. 2 & 3, p. 30).

(6) Comparison with other Areas.

It was at one time customary to regard the Ordovician igneous rocks of Wales as forming, for the greater part, two series: a lower series ranging in age from Arenig to Llanvirn, and occasionally lasting until Lower Glenkiln (Llandeilo) times; and an upper

series of Upper Glenkiln–Lower Hartfell (Bala) age. The former are widely distributed in Wales—throughout the north—Cader Idris,[1] the Arenigs,[2] and southwards to Llandrindod–Builth[3] and

Fig. 2.—*Section across the Llanwrtyd Anticline (see map, Pl. II & p. 27).*

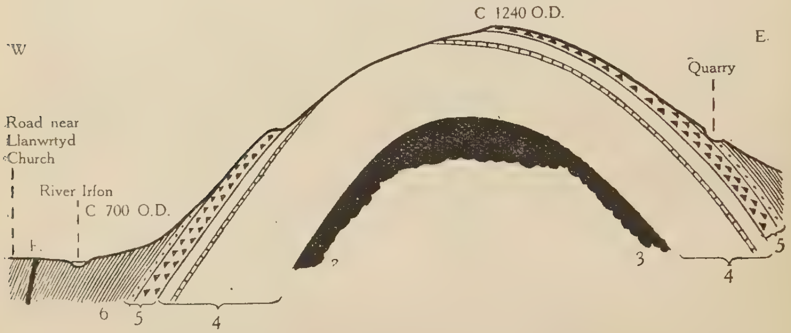
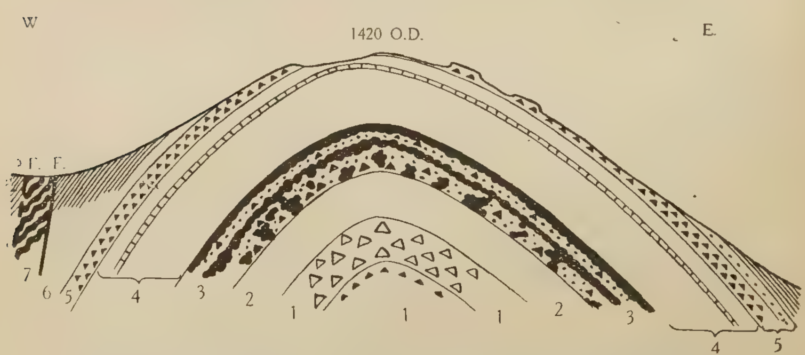


Fig. 3.—*Section across the Llanwrtyd Anticline (see map, Pl. II & p. 25).*



Scales: Horizontal, 6 inches = 1 mile. Vertical, 1 inch = 440 feet.
[The beds are numbered in accordance with the classification tabulated on p. 18.]

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[1] A. H. Cox & A. K. Wells, 'The Ordovician Sequence in the Cader Idris District (Merioneth)' Rep. Brit. Assoc. (Manchester, 1915) p. 424.

[2] W. G. Fearnsides, 'On the Geology of Arenig Fawr & Moel Llyfnant' Q. J. G. S. vol. lxi (1905) p. 608.

[3] H. Woods, 'The Igneous Rocks of the Neighbourhood of Builth' *Ibid.* vol. l (1894) p. 566.

Pembrokeshire.[1] The latter, so far as known at present, appear more restricted in their distribution, and are best known in the Cader-Idris and Snowdon districts.

It was natural to suppose that the Llanwrtyd rocks were of the same age as those at Builth and belonging to the lower series. We have shown, however, that the Llanwrtyd rocks are of Upper Glenkiln (Lower Bala) age: that is, contemporaneous with the Mydrim Limestone of South Wales. Now, the Snowdonian Volcanic Series rests conformably on beds yielding an Upper Glenkiln fauna,[2] and is overlain by beds containing large *Diplograpti* which indicate a very low horizon in the Hartfell (Bala).[3] The volcanic rocks in the Bala country occupy a similar position. Miss G. L. Elles informs me that they are immediately overlain by shales which yield exactly the same fauna as the beds overlying the igneous series of Llanwrtyd. In the Bala country, as at Llanwrtyd, the fossiliferous horizon is succeeded by a great thickness of unfossiliferous black slates and shales. The evidence is, therefore, conclusive, that the Llanwrtyd igneous rocks are of the same age as the Upper Series of Snowdonia, Cader Idris, and the Bala country.

The presence of the remarkable 'spilite-breccia,' as well as the rhyolitic flow-breccia, at Llanwrtyd seems to indicate that the centre of effusion of the rocks was not far distant. It may have formed an isolated centre of eruption on the sea-floor in Upper Llandeilo to Lower Bala times.

I am permitted, by the kindness of Prof. A. H. Cox, to give some further details of correlation with the series in the Llandrindod–Builth area. The southern part of this area was investigated by Mr. H. Woods in 1894, and he came to the conclusion that the igneous rocks were, for the greater part, pre-Lower Llandeilo in age. Dr. H. Hicks, in the course of the discussion on the paper, stated that he had concluded that the contemporaneous volcanic rocks were quite at the base of the Llandeilo Series and mainly associated with the Llanvirn Beds—as in Pembrokeshire and North Wales. The latter opinion has been confirmed by Prof. Cox, who informs me that the volcanic series includes typical spilites, that it rests upon beds yielding *Didymograptus bifidus*, and is overlain by deposits of Llandeilo age yielding *Ogygia buchi.*

The existence of two volcanic cycles in the Ordovician of Wales is thus confirmed by the presence of representatives of the two series in the Builth and Llanwrtyd districts respectively. The suggested correlation of the Llanwrtyd rocks is shown in the appended table (p. 32).

[1] A. H. Cox, 'The Geology of the District between Abereiddy and Abercastle (Pembrokeshire)' Q. J. G. S. vol. lxxi (1915–16) p. 273.

[2] W. G. Fearnsides, 'Geology in the Field' Jubilee Vol. Geol. Assoc. (1910) p. 798.

[3] G. L. Elles, Q. J. G. S. vol. lxv (1909) p. 193.

Correlation of the Llanwrtyd Rocks.

	Llanwrtyd.	Builth.	Cader Idris.[1]	Arenig.[2]	Pembrokeshire.[3]	West Carmarthen.[4]	Shropshire.[5]
Bala Limestones.						Bala Limestone.	Bala Shales and Ashes,
Mydrim Shales.	Unfossiliferous Slates.		Talyllyn Mudstones (unfossiliferous).	'*Dicranograptus* Shales' with Derfel Limestone near the base.	[Fault.]	[Upper] *Dicranograptus* Shales.	with Spy Wood Grit at the base.
Mydrim Limestones.	Fossiliferous Shales. Upper Ashes. Slates. Spilites. Slates (fossiliferous). Lower Ashes [base not seen].	[Silurian unconformity.]	Fossiliferous Shales. Upper Acid Series (Ashes, etc.). Llyn Cau Mudstones. Spilites (Upper Basic Series). Llyn-y-Gader Slates and Ashes.	? Upper Ashes of Arenig. ? Daerfawr Shales.	Castell Limestone.	*Leptograptus* Limestone (=Mydrim Limestone).	Rorrington Shales, containing *Nemagraptus gracilis*.
Hendre Shales and Llandeilo Flags.		Llandeilo Flags.	Pisolitic Iron-Ore. Lower Basic Series.	Lower Volcanic Series of Arenig.	*Dicranograptus* Shales (=Hendre Shales).	*Dicranograptus* Shales (=Hendre Shales). *Asaphus* Ash.	Meadowtown Calcareous Beds.
Murchisoni Beds.		Volcanic Series.			*Murchisoni* Shales, *Murchisoni* Ash, and Llanrian Volcanic Series.	*Murchisoni* Beds, with ash-band in the middle.	*Murchisoni* Shales. Weston Flags. Stapeley Volcanic Series.
Bifidus Beds.		*Bifidus* Shales.	Cefn Hir Ashes. *Bifidus* Slates.	Platy Ashes. *Bifidus* Slates.	*Bifidus* Shales.	*Bifidus* Shales.	*Bifidus* Shales.

[1] A. H. Cox & A. K. Wells, 'The Ordovician Sequence in the Cader Idris District (Merioneth)' Rep. Brit. Assoc. (Manchester, 1915) p. 424.
[2] W. G. Fearnsides, 'On the Geology of Arenig Fawr & Moel Llyfnant' Q. J. G. S. vol. lxi (1905) p. 608.
[3] A. H. Cox, 'On the Geology of the District between Abereiddy & Abercastle (Pembrokeshire)' *Ibid.* vol. lxxi (1915-16) p. 273.
[4] D. C. Evans, 'The Ordovician Rocks of Western Carmarthenshire' *Ibid.* vol. lxii (1906) p. 597.
[5] C. Lapworth & W. W. Watts, 'The Geology of South Shropshire' Proc. Geol. Assoc. vol. xiii (1893-94) p. 297.

(7) Conclusion.

When this investigation was nearly complete, we exhibited a series of specimens from Llanwrtyd at the conversazione of the Geologists' Association in November 1920. We learnt then that Mr. W. Le Lacheur, F.G.S., had for several years been interested in the district, and had examined petrographically most of the rock-types. Mr. Le Lacheur had, therefore, a prior claim to publish the results of his work, and we wish to record our sincere appreciation of his great kindness in allowing us to publish this paper. Not only has he allowed us access to his collection of rocks and slides, but he has also placed at our disposal the results of his own observations in the field.

We also wish to express our thanks to Miss G. L. Elles for the determination of the graptolites; to Prof. A. H. Cox for valuable suggestions and for reading part of the manuscript; and to Mr. A. K. Wells for reading the manuscript, and for helpful criticism.

Part II. Petrographical. (By S. W. W.)

(1) Introduction.

It may be stated at the outset that the dominant feature of the igneous rocks which are here described is the almost universal occurrence of albite. All the rocks, with the exception of the Pen-y-banc intrusion, belong to the spilite-keratophyre series as defined by Mr. H. Dewey & Dr. J. S. Flett.[1] The lavas are essentially albite-bearing rocks, the Upper Ashes resemble quartz-keratophyres in composition, while the other pyroclastic rocks of the series have, without exception, spilitic affinities.

Prof. A. H. Cox[2] has noted the predominance of pyroclastic rocks among those of spilitic composition, and the Llanwrtyd district affords yet another example of this feature, which may be correlated with high viscosity of the magma.

The occurrence of spilitic rocks at the horizon defined above (p. 31) is interesting; but remarks on this matter may be deferred until the petrography of the rocks has been outlined.

The descriptions follow the stratigraphical order of the rocks.

(2) The Lower Ashes and Breccias.

The features presented by these rocks in the field have already been noted (p. 18). Microscopical examination of the typical rock shows that it consists of fragments, originally glassy, set in a silicified matrix which presents a flinty or felsitic appearance.

[1] Geol. Mag. 1911, pp. 202, 241.
[2] Rep. Brit. Assoc. (Birmingham, 1913) p. 497.

Devitrification has everywhere affected the fragments, but the original character is often indicated by well-developed perlitic cracking. In other fragments, commonly of a slightly greenish hue, minute felspar-crystals may be distinguished; but their nature is much obscured by the greenish decomposition-products of the glass. A flow-structure is generally apparent, and the rock from which the fragments were derived was probably a fine-grained spilite. A point of some interest is the transition in one fragment from a fine-grained spilite (as described above) to a true perlitic rock. We appear here to have evidence of a spilite-glass, which in places carried felspar-microlites and in others developed perlitic cracking (Pl. I, fig. 1). The fragments commonly show a smooth or rounded outline. They are accompanied by a few greatly-altered felspar-crystals.

The appearance of these rocks in the field justifies the use of the appellation 'rhyolitic' or 'felsitic,' while the perlitic texture is further suggestive of such a nature. We have shown that this same material passes into a rock of spilitic appearance; but it must be admitted that the composition of the felspar is indeterminable. Further, it is unlikely that analysis would afford any conclusive evidence of the affinities of the rock, since the original composition has been radically changed.

Whether the rock is a flow-breccia or not, it is difficult to determine. The contrast between rock-fragment and matrix seems too pronounced to reconcile with autobrecciation; yet an absence of that mixture of rock-types which would probably result from explosion is significant. The original glassy nature of the fragments points to rapid cooling or to high pressure, while the absence of marked vesicularity is a point of some interest as possibly indicating high pressure. Vesicular glass is certainly a characteristic explosion-product, but it appears more likely that a non-vesicular glass would be formed during submarine eruptions, where the pressure of the superincumbent water-column helped to imprison the fluxes. Now, Mr. J. F. N. Green [1] considers autobrecciation to be a submarine feature; hence we may perhaps take the characters of the glass as indicative of submarine flow-brecciation.

It may be pointed out, however, that no definite conclusion as to the origin of the rock is possible in the absence of wider exposures. The horizontal extent of the breccias would clearly have a most important bearing on the question; but this cannot be determined, since the rocks are exposed only in the core of the anticline.

(3) The Spilite-Breccias and Spilites.

The spilite-breccias occurring below the flows seem to be of somewhat local distribution, and, so far as the rather poor exposures show, are better developed on the south of the Nant-Cerdin Valley than on the north.

[1] 'The Vulcanicity of the Lake District' Proc. Geol. Assoc. vol. xxx (1919) p. 157.

The range in size of the spilite-blocks as seen in the hand-specimen has already been noted. The larger blocks are identical with the rock of the flows above. Under the microscope much smaller fragments are to be seen, mixed with a few pieces of felsitic rock and many broken quartz- and felspar-crystals. All these are set in a murky brownish-black matrix, probably decomposed glass-dust, but now quite unresolvable.

While the spilite-fragments compare in general characters with the lavas described below (p. 36), significant differences are not wanting. It is important to note, for instance, that a good flow-structure is common in the smaller fragments, but absent in the spilite-flows. This points to a much lower viscosity, and suggests that the fragments were derived from a rock which crystallized in the deeper parts of some vent, where conditions of flow were accompanied by that retention of fluxes which commonly characterizes the hypabyssal and plutonic phases. As against this, however, is the fact that the spilite-fragments are decidedly of finer grain than the overlying lavas, a fact not easily reconciled with high flux-content and crystallization at relatively great depth. Moreover, not a few of the fragments show a remarkable development of small chlorite-filled vesicles. These vesicles make up at least 50 per cent, by volume, of the rock, and impart to it a quite remarkable appearance. This, again, points to high gaseous content and uniform pressure; but the fragments in question can hardly have crystallized under the same conditions as those showing good flow-structures, which are generally non-vesicular.

The fragments are either ragged in outline (when non-vesicular), or they exhibit beautiful bogen-struktur with the very characteristic concave outlines of broken vesicles (Pl. I, fig. 2).

Secondary rearrangement of the matrix has produced peculiar spherical bodies which present a pisolitic appearance. Certain crystal-tuffs, described by Dr. Herbert H. Thomas from the Lower Llanvirn Beds of the Carmarthen area, show this feature. A possible phosphatic composition is suggested.[1]

Mr. C. I. Gardiner & Prof. S. H. Reynolds, in their paper quoted above (p. 20) come to no decision as to whether the spilite-breccia which they describe is a flow-breccia or an explosion-product. There seems little doubt that the Llanwrtyd rock is of the latter nature: that is, it is an agglomerate. There is, as we have noted, considerable variation in the nature of the spilite-fragments. Mr. J. F. N. Green[2] has remarked, with reference to the autobrecciation of a submarine lava, that the

> 'mixed mass . . . will form an intricate mixture of blocks, differing slightly in vesicularity, crystallization, proportion of phenocrysts, etc., cemented by similar material.'

In this case the variation in the blocks is more than slight, and

[1] 'The Geology of the South Wales Coalfield, pt. x: The Country around Carmarthen' Mem. Geol. Surv 1909, p. 35.

[2] Proc. Geol. Assoc. vol. xxx (1919) p. 161.

the cementing-material in no way similar. Further, if bogenstruktur is of any value whatever as a pyroclastic criterion, the nature of the rock is determined beyond doubt. In any case, the limited lateral extent of the bed and the admixture of broken crystals must be considered significant, and there can be little doubt that the breccias mark the site of one or more vents.

The spilites present no very unusual features. The normal lavas, occurring in pillows, are pale grey-green vesicular rocks, invariably weathering brown. Under the microscope the rock is seen to be composed, in the main, of a number of felspar-laths; there is little or no sign of fluxional disposition, which points to a high viscosity in the magma. This absence of fluxion-structure has been observed elsewhere in rocks of the spilite-keratophyre suite.[1]

We follow Dr. F. H. Hatch[2] in restricting the term 'pyroclastic' to explosion-products. Dr. Alfred Harker seems to include flow-breccias under this term.[3]

[There seems to be some difference of emphasis in recent petrological writings, in relating the volume of a tuff to the properties of the magma. Prof. A. H. Cox (see p. 33) thinks it probable that the massive tuffs of spilitic series are due to high viscosity of the magma. He quotes Dr. H. H. Thomas (see above), as stating that the keratophyres of Skomer Island show an absence of fluxion-structure which suggests high viscosity. It is to be noted, however, that Dr. Thomas emphasizes the rarity of pyroclastic rocks in the Skomer Series, which thus appears to be an exception to a rule that certainly holds in many Welsh localities. Further, it is interesting to note that Weinschenk states explicitly[4] that the amount of associated tuff depends on the gaseous content of the magma—'the more gas, the more dust-like material hurled forth by its escape.' High gaseous content, however, should lower the viscosity of the magma.]

On the whole, the rocks are of even grain, although some might be described as microporphyritic. There are, moreover, occasional true phenocrysts, as well as glomeroporphyritic groups of felspar-crystals.

The rocks differ from certain typical spilites (for example, those of Pentire Point and many from Merioneth) in being relatively coarse. The felspars are not, on the whole, microlitic, and they are somewhat wanting in the bifurcating and swallow-tail aspect so characteristic of the felspars of these rocks in general. In some cases, indeed, the term 'andesitic' would not be a misnomer in

[1] See H. H. Thomas, Q. J. G. S. vol. lxvii (1911) p. 195.
[2] 'Text-Book of Petrology: the Igneous Rocks' 1914, p. 291.
[3] 'Petrology for Students' 1908, p. 277.
[4] 'Fundamental Principles of Petrology' English transl. by Johannsen, p. 43.

regard to their structure, but the composition of the felspar makes it unsuitable. It is true that felspar-microlites do occur in the interspaces, but they seem to be due to the devitrification of an interstitial glass, a view supported by the occurrence of patches of a true microlitic spilite, differing markedly in texture from the mass of the rock.

Most of the felspar appears to be albite giving extinction-angles in symmetrically-cut sections ranging from 10° to 16°, and having a refractive index below that of balsam. Carlsbad twinning is common, and certain laths giving straight extinction are probably orthoclase. The felspar is, on the whole, fresh, although signs of incipient alteration to a kaolin-like substance are not wanting.

Filling the spaces between the felspars is a brownish murky substance, which presumably arises from the decomposition of interstitial glass. In some cases it appears to be aggregated into spots, and it is also associated with granules of carbonates, imparting to them a dusty appearance.

Iron-ores, both primary (magnetite) and secondary (pyrites), occur.

No unaltered ferromagnesian mineral occurs in these rocks. Certain chloritic patches fringed with iron-ore are probably pseudomorphs after some basic mineral. The iron-ore seems to have separated from the chlorite, whence it may be inferred that the original mineral had a high iron-content. It may be pointed out, however, that neither hypersthene nor even amblystegite contains enough iron to yield the excess which this implies, assuming that the chlorite is intermediate in composition between amesite and serpentine. The selvage of iron-ore is in general regular, and does not vary much in width with the size of the chlorite-area. These areas show two varieties of the mineral: the central parts are occupied by a chlorite of fibrous nature, sub-radiate in arrangement and possessing a relatively high birefringence. Adjacent to the iron-ore rim is a zone of chlorite which is nearly isotropic: this zone may represent an area from which the surplus iron has been extracted.

Vesicles are of various kinds. Some are filled with fibrous chlorite, others, especially the larger, with calcite. Many, however, have a narrow border of chlorite, the interior being filled with calcite, as is the normal arrangement in the Cornish spilites. Still others are filled in the main with calcite, which encloses rounded aggregates of chlorite. The presence of the latter suggests that the post-volcanic periods of chloritic and calcitic deposition were not always distinct and successive, but may have alternated and overlapped. In a few cases, a rim of secondary water-clear albite intervenes between the margin of the vesicle and the chlorite.

A further point of interest as regards the vesicles is the common occurrence of an encircling zone of dark spilite. The latter differs from normal spilite in containing fewer microlites, and in its more advanced stage of decomposition. The relation of the dark

peripheral area to the normal vesicle varies: in some cases it forms a mere selvage, in others is observed a large circular patch of dark material in which are set a number of rounded areas of calcite and chlorite. It appears most likely that this effect is due to the corrosive action of the liquid filling the vesicle on its walls. This liquid may well have been alkaline, and the local leaching action, coupled with the replacement of lime by soda, doubtless contributed to the calcite-infilling of the vesicles.[1] A conspicuous feature is the tangential arrangement of felspar-laths on the outer edge of the areas of dark spilite (Pl. I, fig. 3).

Before leaving the subject, we may remark that, if a corrosive liquid be accepted as an adequate explanation of the dark spilite-rims, then we may suspect that much of the murky alteration-product of the ground-mass owes its origin to a similar action more widely diffused. This gains support from the fact that the degree of alteration bears no obvious relation to the degree of surface-weathering of the rock.

Cases in which the still fluid lava has ruptured a vesicle-wall, and partly infilled it, have been observed[2] (Pl. I, fig. 4).

We may note, in concluding the account of the normal spilites, that a slide showing the junction of a lava with associated chert revealed a somewhat unexpected feature. Wisps and strings of spilite are seen to be included in the chert, and scattered felspar-laths occur throughout the latter. It seems clear from this that the chert does not represent material deposited in the interspaces of the pillows subsequent to cooling, but rather that it is sediment which was involved in the rolling action of the pillows during eruption.

The lavas which form the centre of Car Cwm do not exhibit the 'pillow' habit; but they do not differ in microstructure from the rocks described above. That they were once vesicular is apparent on microscopical examination; the fact is, however, to some extent concealed by the extreme alteration which has taken place. In most cases, these rocks are little more than a mass of secondary minerals. One slide shows a fresher rock, and serves definitely to link the massive spilites with the normal pillowy type.

(4) The Tuff-Bands in the Hardened Mudstones.

Tuff-bands of varying thickness occur throughout this division. The majority are fine-grained black rocks weathering white (as so clearly described by Murchison), and they are very similar to the hornstone facies of the Upper Ashes; for that reason, they will not be separately described.

Certain coarser bands occur, however, and these are of greater interest. Two types will be considered—

[1] See J. F. N. Green, Proc. Geol. Assoc. vol. xxx (1919) p. 177.

[2] See A. Harker, 'The Tertiary Igneous Rocks of Skye' Mem. Geol. Surv. 1904, pp. 331, 342, 399–401.

(*a*) The first type comes from a horizon not far above the spilites. It is a well-bedded rock intermediate in character between the crystal-tuffs and the lithic tuffs, as defined by L. V. Pirsson.[1] It consists of a number of small fragments, many not exceeding 1 mm. in diameter, of an ill-defined felsitic character, mixed with many felspar-crystals, complete or fragmental, and a few quartz-grains. The fragments are in close juxtaposition, only a little argillaceous material intervening. Some few are vesicular, and an occasional spilitic fragment may be found. It is remarkable that the underlying lavas have contributed so little to the rock, which would appear to have been derived from a relatively acid magma.

(*b*) The second type forms a fairly constant band at a horizon just below the Ashy Limestone. It is a beautiful example of a lithic tuff, as defined by Pirsson. It is chiefly composed of fragments of spilite in close juxtaposition. The fragments were apparently once glassy, and, as in the Lower Breccias already described, the decomposition-products of the glass tend to obscure the felspar-laths.

Filling the angular spaces between the fragments is a somewhat remarkable substance, which appears at first sight to be a vesicular calcite: that is, calcite-areas dotted over with small chlorite-filled vesicles. This seems to be a case of the almost complete calcification of a vesicular glass.

The rock moreover carries small pisolitic bodies as described in the spilite-breccias, and a fragment of an echinoderm-plate was also found.

(5) The Upper Ashes.

These beds weather like typical ashes, and compare closely in hand-specimens with the finer parts of the Cefn-Hir Ashes recently described from North Wales.[2] Under the microscope, the rocks are very similar to ashes from the Lower Acid Series of the same authors.[3]

The rocks are of thoroughly acid composition, and consist of a number of large crystals (some broken) of quartz and felspar, set in a silicified matrix which may be described as felsitic. In places, however, the allothigenous fragments of quartz and felspar in the matrix are larger, and it is then possible to distinguish them from secondary quartz-granules, and to recognize their angular and unworn character and the clastic appearance which they impart to the rock. This matrix must, before consolidation, have been of the nature of an unsorted volcanic sand.

Turning now to the larger constituents, we may note that, while the quartz is commonly angular, this is not a universal feature, and

[1] Amer. Journ. Sci. ser. 4, vol. xl (1915) p. 193.
[2] A. H. Cox & A. K. Wells, Q. J. G. S. vol. lxxvi (1920–21) p. 278.
[3] Rep. Brit. Assoc. (Manchester, 1915) p. 424.

rounded grains are frequently to be found. Much of the quartz is traversed by curved fractures. In some cases a crystal has been broken in place along such fractures, and the fragments separated by matrix. Since the rock is extensively silicified, it may be possible to refer this shattering to strains set up during the crystallization of the secondary quartz, or alternatively to the setting of a siliceous gel. The quartz-grains show beautiful secondary outgrowths as a result of the silicification.

Before leaving the subject of the larger quartz-grains, it may be well to refer at greater length to the curved fractures mentioned above, which give rise to concave outlines. Despite a somewhat loose current usage, we cannot apply the terms bogen-struktur or aschen-struktur in this case. These terms, introduced by O. Mügge,[1] seem to have been used explicitly by him with reference to the concave fragments produced by the breaking-up of glassy vesicular rocks. Moreover, Pirsson, by proposing to substitute the term vitroclastic, which is self-explanatory, clearly recognizes the difference between the concave outline of a broken vesicle and conchoidal fracture.[2] At the same time, it does appear that these curved fractures are especially common in tuffs. Many cases of perfectly straight fractures have been observed in true rhyolites, although the exact mechanical differences which determine the formation of a straight or a curved fracture are difficult to define. It is necessary to recall in this connexion that Prof. W. W. Watts [3] proved, many years ago, that true perlitic cracks could be formed in the quartz-phenocrysts of a porphyritic pitchstone.

A further interesting feature of the quartz-fragments is the frequent occurrence of the 'resorption-inlets' so commonly seen in rhyolites (Pl. I, fig. 5). Prof. A. H. Cox has described a similar feature in the tuffs of Abereiddy Bay,[4] and Dr. J. S. Flett describes examples from the quartz-keratophyre tuffs of Devon.[5]

The felspar-crystals attain a greater size than do those of quartz. They are almost invariably altered to an opaque substance, probably of the nature of kaolin, which outlines the cleavages and covers the surfaces generally. A few flakes of secondary mica are occasionally developed.

While sometimes showing good form, the felspar frequently presents the appearance of having been brecciated in place like the quartz. Angular pieces are seen to surround some larger fragment, and their outlines show clearly that they once formed part of it.

Most of the felspar is undoubtedly albite, and some of it seems

[1] Neues Jahrb. Beilage-Band viii (1893) p. 648.
[2] Amer. Journ. Sci. ser. 4, vol. xl (1915) p. 198.
[3] Q. J. G. S. vol. l (1894) p. 367.
[4] *Ibid.* vol. lxxi (1915–16) pp. 298 *et seqq.*
[5] 'The Geology of the Country around Newton Abbot' Mem. Geol. Surv. 1913, p. 58.

identical with the 'chequer-albite' of F. Becke; this variety is also found in the Devon quartz-keratophyre tuffs.[1] The effect under crossed nicols is due to the splitting-up into a number of small rectangular patches, half of which extinguish simultaneously. Becke supposed the structure to be secondary,[2] and, in support of this surmise, we may note that in these rocks 'chequering' sometimes affects the periphery of a crystal only.

Indications of a micropegmatitic fringe can be seen round certain of the felspars—a feature referable to the devitrification of the original matrix prior to silicification.

In addition to crystals of quartz and felspar there are bombs of fine-grained spilitic material, as well as pumiceous fragments the vesicles of which have been pulled out into long tubes and filled with secondary quartz. Among the smaller recognizable constituents are crystals of zircon, often associated with iron-ore. The 'Lower Acid' tuffs of the Cader-Idris district also show this feature.

It thus appears that these rocks compare closely with those described as quartz-keratophyre tuffs in other districts, the resemblance extending even to points of minor detail.

Banded ashes occur, as already stated (p. 22), on the eastern side of Garn Dwad, following upon the coarser keratophyric ashes just described. There is some sign of passage between them and the rocks below.

A typical example shows, under the microscope, a succession of bands, not very clearly defined, ranging in thickness from 3 mm. to less than 1 mm. The darker bands seemingly owe their colour to magnetite-dust, which defines the bedding-planes to some extent.

Generally speaking, the rock is a fine-grained aggregate of quartz and felspar showing local chloritic and limonitic staining. Calcite is abundantly distributed, especially in the paler bands. The quartz is angular, and full of inclusions. The felspars retain in general a lath-shape, and, although it is not possible to measure extinction-angles in such small fragments, the refractive index is below that of balsam in most cases. Thus these rocks agree with their associates in being predominantly albitic.

The fine-grained facies of the Upper Ashes, to which the term hornstone or hälleflinta is applied, appears to compare in many respects with the 'china-stone ashes' which are so widely distributed in the Llanvirn Beds, as at Hope Dingle, Abereiddy Bay, and in the Dolgelly district. The white weathering is very characteristic. Under the microscope, the rocks are seen to be almost identical with the Ynys-Castell Ashes, as described by Prof. A. H. Cox.

[1] Mem. Geol. Surv. 1913, p. 58.
[2] Denkschr. K. Akad. Wissensch. Wien, vol. lxxv (1913) p. 128.

(6) The Intrusion.

The absence of intrusive types associated with the suite of rocks exposed at Llanwrtyd is rather remarkable. In many other Welsh localities where spilitic rocks occur, 'diabases' of varying affinities are very abundant. The only rock in the Llanwrtyd district for which an intrusive origin is suggested is that exposed over a limited area near Pen-y-banc Farm. As already stated, no intrusive contacts can be seen, but the lenticular shape of the mass is suggestive, and makes it improbable that the rock is a lava.

The rock was described by Murchison as a 'greenstone,' and its general appearance is in accord with such a name. Under the microscope, the rock is seen to be composed of a number of chlorite- and bastite-pseudomorphs after olivine, set in a groundmass of felspar-laths and granular augite.

The felspar appears to be albite, but it lacks that fresh—almost primary—character of the felspar seen in the spilites, and is clearly the product of a secondary change.

The augite is pale green to colourless. Some few grains are relatively idiomorphic, but many are shapeless. The patchy appearance of the rock in the hand-specimen (p. 24) seems to be due to the irregular grouping of the augite-granules.

A few grains of a dark-brown strongly-pleochroic hornblende also occur. It has many of the characters of barkevikite, but its extinction-angles are too high for that mineral. Its optical sign is positive, and it appears to be identical with the mineral described by Dr. Herbert H. Thomas from the marloesites of Skomer Island,[1] and by Dr. A. Harker from the mugearites of Skye.[2] It is certainly secondary after augite in some cases.

The pseudomorphs after olivine present rather unusual characters. In some cases, the original mineral has been replaced by a green chlorite which is nearly isotropic. The characteristic shape of the olivine is often preserved, and the arcuate alteration-cracks (such as are seen in normal serpentinous pseudomorphs) are very apparent (Pl. I, fig. 6). Other pseudomorphs present some of the characters of bastite; they are green and pleochroic, with a relatively high birefringence and a well-marked cleavage.

Scattered through the ground-mass are large plates of ilmenite, altering to secondary sphene. They are sometimes penetrated by felspar-laths in a subophitic manner. Scapolite also occurs in fair quantity, and presumably contains the lime set free during albitization.

Since the rock seemed to be related to some of the Skomer-Island types, slides were submitted to Dr. H. H. Thomas, who kindly informed me that the rock compared in some respects with the marloesites of that locality. In his opinion, it was best

[1] Q. J. G. S. vol. lxvii (1911) p. 198.
[2] 'The Tertiary Igneous Rocks of Skye' Mem. Geol. Surv. 1904, p. 262.

described as an albitized olivine-basalt. He also compared it with certain dykes in the pre-Cambrian rocks of Pembrokeshire described by him.[1]

The age of the intrusion is unknown. Evidence has been brought forward (p. 24) which indicates that it preceded the formation of the western boundary-fault. This fault is later than the folding, since it truncates the northern end of the anticline. The latter structure is approximately Caledonian in trend. Farther than this it is not possible to go.

(7) Summary and Conclusions.

The igneous rocks exposed at Llanwrtyd Wells are predominantly pyroclastic in nature, while their composition places them in the spilite-keratophyre series almost without exception. There is a noteworthy absence of intrusive rocks.

The succession begins with 'rhyolitic' breccias the exact nature and composition of which are rather in doubt. While not excluding the possibility of their being flow-breccias, we have taken the available evidence as indicating a probable agglomeratic nature.

The spilite-breccias which occur at the base of the flows are certainly of explosive origin. They pass gradually upwards into spilites which are true albite-bearing rocks. A normal pillowy facies can be distinguished from a massive non-pillowy type.

The spilites are succeeded by a considerable thickness of sediments, in which occur bands of hälleflinta and of crystal-tuff; while at the top of the series is a good development of quartz-keratophyre tuffs.

The close resemblance between some of the pyroclastic types described, and those of other areas differing widely in horizon, tends to emphasize the unity and genetic individuality of the spilite-keratophyre suite.

The Pen-y-banc intrusion is a somewhat peculiar rock. It has been possible to compare it with the marleosites of Skomer Island and with certain pre-Cambrian dykes in Pembrokeshire. Its age is unknown, and it falls apart from the rest of the series, its only point of affinity with these rocks being the presence of albite.

It may be remarked, in conclusion, that it is interesting to find spilitic rocks so high in the Ordovician sequence. Dr. Harker has indicated in his recent address to the Geological Society[2] that Llandeilo times witnessed a change in the stress conditions, which effected a general replacement of spilites by andesites. He notes instances, however, of the persistence of the spilitic type, as on the summit of Cader Idris. The Llanwrtyd district affords another instance of this persistence; the sequence here is closely parallel

[1] H. H. Thomas & O. T. Jones, Q. J. G. S. vol. lxviii (1912) pp. 389–90.
[2] Q. J. G. S. vol. lxxiii (1917–18) p. lxxvi.

to that on Cader Idris, as appears from the correlation-table (p. 32).

I wish to express my very great indebtedness to Mr. A. K. Wells for much help and encouragement during my work. I have further to thank him for the photomicrographs which illustrate this paper. My thanks are also due to Prof. W. T. Gordon for critically reading the manuscript, and to Dr. H. H. Thomas for examining slides of the intrusion and advising me as to its affinities. I also desire to associate myself with my co-author in the thanks expressed to Mr. W. J. Le Lacheur, to whom I am especially indebted for the loan of microscope-slides.

EXPLANATION OF PLATES I & II.

Plate I.

Fig. 1. 'Rhyolitic' breccia, showing passage in one fragment from a perlitic glass to a fine-grained spilite: × 20. (See p. 34.)

2. Spilite-breccia, showing in the lower part of the field a highly vesicular spilite-fragment. Well-developed bogen-struktur is seen above: × 20. (See p. 35.)
3. Spilite, showing vesicles surrounded by dark spilitic rims, with tangentially arranged felspar-crystals: × 20. (See p. 37.)
4. Vesicle in spilite. The wall has been ruptured, admitting the fluid magma, and secondary albite is seen outlining the original vesicle-wall: × 20. (See p. 38.)
5. Quartz-keratophyre tuff from the Upper Ashes. Embayed quartz-fragments are seen, with a felspar-crystal in the upper part of the field: × 20. (See p. 40.)
6. Intrusion (albitized olivine-basalt). A well-formed bastite-pseudomorph after olivine in the centre of the field, with others in the lower part. Several large plates of ilmenite are seen enclosing the ends of felspar-laths subophitically. Fluxion-structure is also well seen: × 20. (See p. 42.)

Plate II.

Geological map of the neighbourhood of Llanwrtyd Wells, on the scale of 3 inches to the mile, or 1 : 21,120.

Discussion.

Prof. A. H. Cox remarked on the great interest of the paper to him, since it dealt with an area so similar to, and yet so distant from, the Cader Idris district which he himself was examining. He had had the advantage, through the Authors' courtesy, of reading a part of the paper, and of examining many of their specimens. The correspondence between the rock-types of the two districts is truly remarkable, and all the more so since it was quite unexpected when the investigation was originally commenced. It was then naturally assumed that the Llanwrtyd rocks would correlate with those in the adjoining Builth area. The proof now

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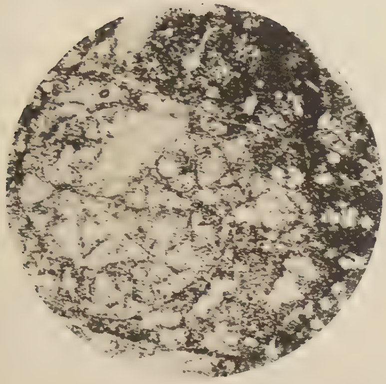

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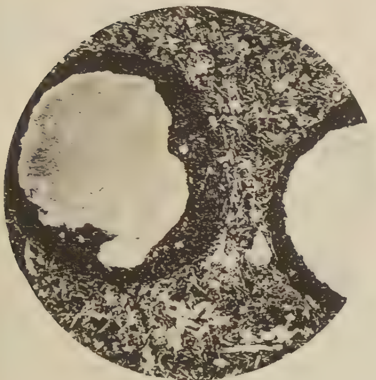

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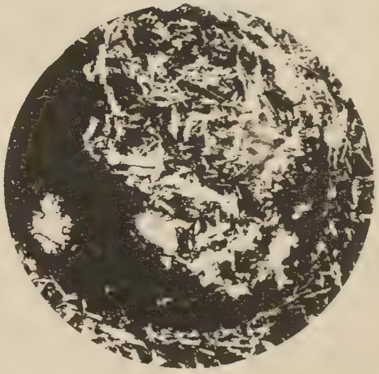

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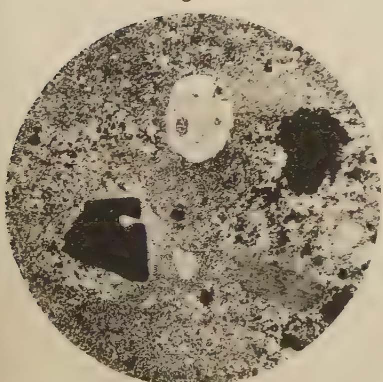

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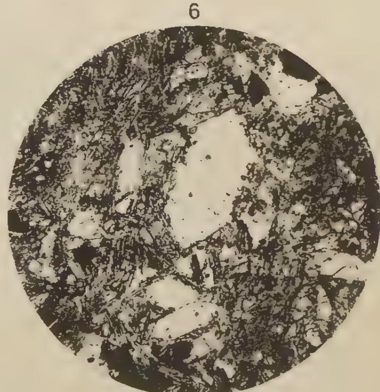


A.K.W. PHOTOMICRO.

IGNEOUS and CLASTIC ROCKS from the
LLANWRTYD DISTRICT.

[Scale: 3 inches = 1 mile, or 1:21,120. The map is oriented north and south.]

brought forward that the Llanwrtyd rocks are on a higher stratigraphical level than those of Builth is an important step in the elucidation of the history of vulcanism in Wales; it gives further support to the sequence determined in the Cader-Idris area where fossils are not easily obtainable, and it raises interesting questions as to the underground extension of these rocks in the areas round Llanwrtyd. Another remarkable point is the great thickness of the zonal deposits, even when due allowance is made for the presence of volcanic rocks. In this respect also, the area allies itself with the more distant Merionethshire regions, and offers a strong contrast to the nearer Carmarthenshire district, where the *Nemagraptus-gracilis* Zone is thin, and contains no suggestion of the existence of volcanic activity.

He would draw attention to the difficulty caused by the present want of agreement as to the exact delimitation of the Llandeilo and Bala Groups. This difficulty confronted all workers on the Ordovician rocks of Wales, and led to undesirable and quite unnecessary complication of the nomenclature. In view of the importance of the horizon, he thought that the Geological Society might well establish a Committee which should consider the question, and lay down a ruling that subsequent writers could follow. He did not know whether there was any precedent for such action, but its advantages seemed obvious.

Miss G. L. Elles expressed the opinion that the horizon of the rocks as indicated by the graptolites was rather later than that surmised by the Authors. She considered the absence of certain characteristic species as significant, the species recorded being those that commonly survived into beds at a higher horizon. She regarded it as interesting that the assemblage recorded was identical with that in the black shales resting upon the Arenig Mountain Volcanics, which were the base of the *Dicranograptus* Slates of North Wales.

In the Builth country there were two fossiliferous horizons above the extrusive volcanic beds, the higher of which contained precisely the assemblage recorded by the Authors from Llanwrtyd. These were, however, cut and altered by the intrusive rocks, and if these were to be regarded as belonging to the same period (as seemed likely), it was hardly correct to say that the rocks of the Builth area were of Llanvirnian age.

Dr. G. H. Plymen said that it was matter for comment that the volcanic sequence described by the Authors contained a lower keratophyric flow and an upper spilitic outburst, the normal succession being that of keratophyric or rhyolitic rocks after spilitic or others of intermediate nature; also, he would have expected the vesicular spilites to overlie those of massive character. The Authors were to be congratulated on registering a case where what might be called 'conventional' volcanic activity was reversed.

Mr. G. M. Part enquired whether there was any evidence to be obtained from the chlorite-pseudomorphs, as to the nature of the original ferromagnesian mineral of the spilites.

Dr. L. D. Stamp, in replying, thanked Prof. Cox for his kind remarks, and agreed that the thickening of the beds on the horizon of the Mydrim Limestone, as one went northwards from South Wales, was very interesting. Llanwrtyd occupied a position approximately half-way between the South Wales exposures (where volcanic rocks are absent on this horizon) and Cader Idris (where the volcanic rocks are so remarkably well developed). In reply to Miss Elles, he said that the correlation of the Llanwrtyd graptolitic horizons with the Mydrim Limestone was based on the tabulated statements in the Geological Survey Memoir on the Haverfordwest district. Only one of the Llanwrtyd species occurred at all commonly on any other horizon in South Wales, while all the others are shown as attaining their maximum development in the Mydrim Limestone. With regard to Dr. Plymen's remarks, it was difficult to make any useful suggestions without going more fully into the facts.

Mr. S. W. Wooldridge, in answer to Mr. Part's query, described the occurrence of the chloritic pseudomorphs in detail; but stated his inability to identify the ferromagnesian mineral which had given rise to the chlorite.

3. SHALES-*with*-'BEEF,' *a* SEQUENCE *in the* LOWER LIAS *of the* DORSET COAST.

By WILLIAM DICKSON LANG, Sc.D., F.G.S., LEONARD FRANK SPATH, D.Sc., F.G.S., and WILLIAM ALFRED RICHARDSON, M.Sc., F.G.S. (Read January 4th, 1922.)

[PLATES III & IV.]

CONTENTS.

PART I. STRATIGRAPHY.

(A) Introduction.

SHALES-WITH-'BEEF'[1] was the name given to some 70 feet of Lias on the Dorset coast, lying above (53) Table Ledge and below (76 a) the *Birchi*-Tabular. The beds consist of paper-shales, marls, indurated bands, and limestone nodule-beds, with numerous,

[1] W. D. Lang, Proc. Geol. Assoc. vol. xxv (1914) p. 313.

more or less impersistent, interbedded seams of fibrous calcite, called 'Beef'[1] by the Officers of the Geological Survey.

Descending to the beach at Charmouth, and there forming reefs on the foreshore, the Shales-with-Beef are the most accessible Lias of that place. Yet they are, perhaps, the least known of all the beds. This is doubtless because of the generally unsatisfactory condition of the fossils found in them, and their consequent worthlessness on the one hand to the native, who finds no sale for such fragmentary and friable remains as the fossils present; while, on the other hand, the geologist seldom finds specimens more than approximately identifiable, and generally obtains completely satisfactory examples from but three or four horizons.

Sir Henry De la Beche described the Lias of this coast nearly a century ago[2]; and, although he generally under-estimated their thickness, the subdivisions that he then made can be approximately correlated as follows, at any rate those five which lie above the Blue Lias limestones:—

(5) Irregular bed of Limestone, with nodular concretions, frequently containing ammonites; 2 feet=*Stellaris* beds (87–89).

(4) Slaty marls, with several thin beds of indurated marl; 67 feet=Black Marl series above *Birchi*-Tabular and below *Stellaris* beds (77–88).

(3) Slaty marls containing small crystals of selenite; 32 feet=Shales-with-Beef (54–76).

(2) Indurated marl, containing small, plicated *Terebratulæ*; 4 feet=Table Ledge (53).

(1) Slaty marls; 18 feet=Saurian shales, Fish-Bed, and Fish-Bed shales (50–52).

In 1860, when Thomas Wright described the Lower Lias of this coast, he but briefly referred to the Shales-with-Beef as

'thick beds of dark marls, which rest on the Table-bed, formed by Broad Ledge. The lower part of these marls contain numerous compressed Ammonites [*Ægoceras Birchii* (Sowerby)] and layers of nodules forming cement-stones.' (Q. J. G. S. vol. xvi, p. 405; and Monogr. Pal. Soc. 1879, p. 49.)

This lower division of Wright exactly corresponds with the topmost 18 feet of the Shales-with-Beef. Thus the 50 feet of strata lying between Table Ledge and the beds with *Microderoceras* are left undescribed.

In his later account (1878–79, 'Monogr. Lias Ammonites' Pal. Soc. pp. 48–51) Wright again omits the greater part of the Shales-with-Beef; for his 'Thick Limestone, "Broad Ledge"' at the top of his '*A. turneri*' Zone (p. 48) is Table Ledge (53); while his 'Nut rocks' at the bottom of his *A. obtusus* Zone (p. 50) is the *Birchi*-Nodular (75 a).

[1] H. B. Woodward, 'The Jurassic Rocks of Britain, vol. iii: the Lias of England & Wales' Mem. Geol. Surv. 1893, p. 65. Applied by the workmen in the Purbeck district (and, probably, elsewhere) to seams of fibrous calcite in the Purbeck Beds; see W. Buckland & H. T. De la Beche, Trans. Geol. Soc. ser. 2, vol. iv, pt. 1 (1835) p. 11 [I am indebted for this reference to Dr. F. L. Kitchin].

[2] Trans. Geol. Soc. ser. 2, vol. ii, pt. 1 (1826) p. 21; and 'Report on the Geology of Cornwall, Devon, & West Somerset' 1839, p. 222.

In the Geological Survey Memoir of 1893 ('Lias of England & Wales' pp. 65–66), H. B. Woodward enumerates nine subdivisions of the Shales-with-Beef, which I correlate as follows:—

[9] 'Firestone Nodules or *Birchii* Bed. Hard irregular and nodular limestone or Cement-stone, with "beef" above and below. It forms one or two beds with iron-stained joints. *Am. Birchii* and clusters of small Ammonites; 1 ft. 6 ins.'=*Birchi*-Nodular and *Birchi*-Tabular, with the intervening paper-shales (75–76 a).

[8] 'Dark shales with band of thin shaly limestone, and occasional nodules of limestone; 10 ft.'=74 q–74 w.

[7] 'Lenticular band of grey limestone with "beef."'=74 p.

[6] 'Dark shales with thin band of limestone in places; [with 5 and 7] 15 ft.'=74 g–74 o.

[5] 'Interrupted band of limestone with "beef."'=74 f.

[4] 'Dark shales and paper-shales, slightly calcareous and micaceous, with indurated bands and seams of "beef." Saurian remains; 25 ft.' =72 b–74 e.

[3] 'Marly cement-stone bed.'=Reef 19 (72 a).

[2] 'Marly shales with iron-pyrites, and thin conspicuous layer in the West Cliff known as the Black Bear;. 25 ft.'=54 a–71 g.

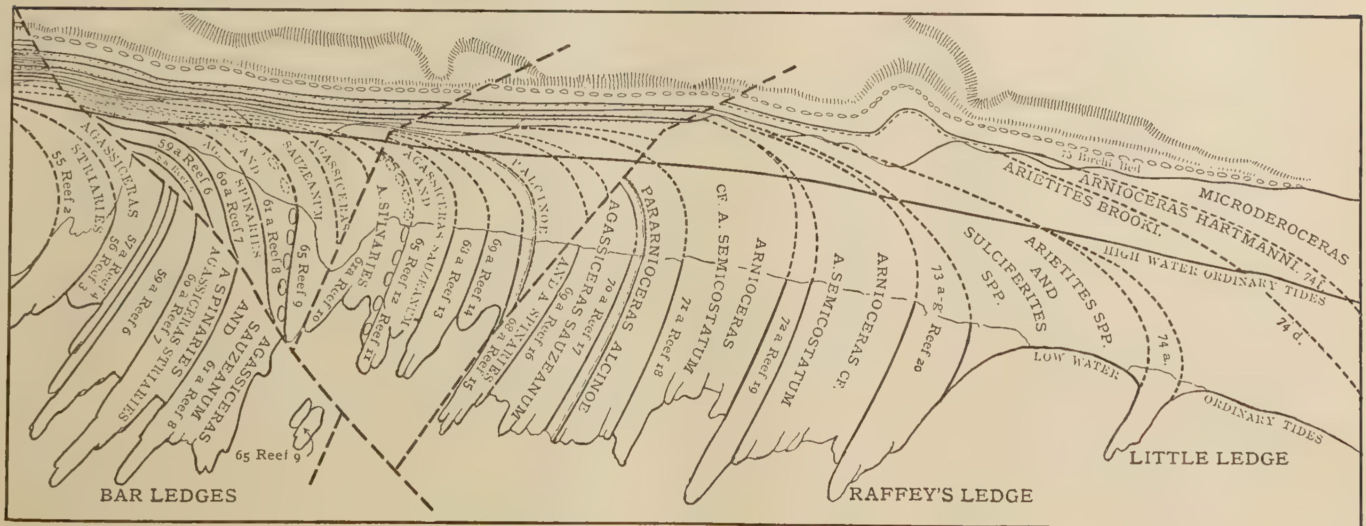
[1] 'Hard Marl or Table Ledge.'=53.

In 1914,[1] I further subdivided these beds, in order to collect from them in detail, hoping thereby to obtain a faunal sequence sufficiently complete to afford a basis of correlation with the Lias of other areas. As the sequence appeared most obvious on the reefs, and the best collecting-ground was there, I simply numbered the reefs, and (with the exception of Reefs 17, 19, 20, and Little Ledge) attempted no correlation with the section on the cliff. Further work has shown that the reefs are not quite in simple sequence, owing to two small faults which cause repetitions (see fig. 1, p. 50). Thus, Reef 8 is on the same horizon as Reef 10, and Reef 9 as Reefs 11 & 12. Also Reef 13 is repeated as Reef 15, and Reef 14 as Reef 16. Therefore, it has been necessary to re-adjust the numbers of the beds; but, so far as possible, the original numbers have been retained, and further subdivisions indicated by adding a letter to the original number. Again, in the 25-inch map published in 1914, the individual reefs were but approximately marked. In the map (fig. 1) accompanying this paper their positions are more accurately indicated, with the faults[2] and repetitions. The ammonite fauna, too, was but superficially treated in the 1914 account, and only two important features stood out: namely, the prevalence of *Arnioceras* in the lower part and the occurrence in Reef 17 of ammonites there referred to *Coroniceras*, but now recognized as *A. alcinoe* and allied species, and placed in a new genus, *Pararnioceras* Spath.

[1] Proc. Geol. Assoc. vol. xxv, pp. 314–15.

[2] [The westernmost fault on the cliff is continuous with the line of fracture across the reefs shown on the map (fig. 1); but it is possible that, on the reefs, the actual fault runs more directly out to sea.—*W. D. L., November 24th, 1922.*]

Fig. 1.—*Map of the lower part of the cliff, the beach, and the foreshore, immediately west of Charmouth. Approximate scale: 22 inches = 1 mile.*



[The distance represented is about 560 yards.]

Since 1914, a great deal of material has been collected; and it has been found desirable to subdivide the horizons still further, in order to arrive at a more exact faunal sequence. Moreover, the cliff-section immediately west of Charmouth has been correlated with the sequence on the reefs. Of course, it is not to be supposed that the minute subdivisions will be found farther along the cliff, or even that the prominent beds at the Charmouth end of the section will necessarily persist as far as Lyme, or to the mile west of Lyme where the Shales-with-Beef occur; the fauna alone will correlate horizon with horizon along the cliff-section, and at isolated exposures inland. But, until the faunal sequence is determined, this correlation cannot be made; and, in order to find the faunal sequence, it is necessary to subdivide a standard section minutely. The accessible western part of the outcrop has therefore been selected for the purpose, and it is hoped that the reason given explains and excuses the subdivision of some 70 feet of shales into more than a hundred horizons.

In 1917, Mr. S. S. Buckman read a paper before this Society on the British Lias, in which he drew attention to the phenomenon called by him faunal repetition.[1] In the same paper, Mr. J. W. Tutcher[2] gave an ammonite sequence in the Bath–Radstock district, in Lias corresponding to that here described. His sequence, from below upwards, was *A. scipionianus*, *A. sauzeanus*, *A. turneri* [*M. birchi*], differing from Buckman's sequence[3] in the last two terms; for Mr. Buckman puts *A. turneri* above *M. birchi*. Thanks to the researches of Dr. L. F. Spath, who has kindly examined my ammonite material from these beds, and contributes a palæontological part to this paper, it has been possible generally to correlate the horizons of the Shales-with-Beef with the three topmost horizons in the Bath–Radstock area just mentioned. The correlation is as follows:—Horizon of *A. sauzeanus* = below (53) Table Ledge to 70 e; *M. birchi* = 74 g–75; and *A. turneri* = 76 a. Thus the beds from 70 f to 74 f are not represented in the Bath–Radstock area. It is true that in Dorset there is a faunal repetition[4] of *Arietites*: thus, there is a lower Arietite fauna in 73 & 74 d, below the *M. birchi* horizon; and an almost exactly parallel Arietite fauna, including the true *A. turneri*, in 76 a & 76 b, above the *M. birchi* horizon. But the specimens of *A. turneri* on which Mr. Tutcher founded his sequence, and on the exact field-relation

[1] Q. J. G. S. vol. lxxiii (1917–18) p. 267.

[2] In S. S. Buckman, *op. cit.* p. 279. Mr. Tutcher does not add *M. birchi* to the top of his sequence. It is evident, however, that he did not suppose that *M. birchi* came between his *A. sauzeanum* and *A. turneri*, but that it was later than *A. turneri*.

[3] *Op. cit.* p. 277.

[4] In these beds faunal repetition is also seen in the *Schlotheimia* [*Sulciferites* Spath] fauna associated with the lower *Arietites*; in the *Coroniceras*-like forms [*Pararnioceras* Spath] in the *P.-alcinoe* bed; in the reappearance of *Agassiceras* above Table Ledge (53), and of *Arnioceras* above the *Brooki* Bed.

of which to *M. birchi* he is (I understand) not absolutely determined, appear to represent the upper Arietite fauna.[1]

What are probably other important stratigraphical results embodied in the present paper are (1) the unexpected position of *A. brooki*[2]; (2) the recognition of one distinct *Arnioceras* horizon at the base, and another at some 20 feet from the top of the series; (3) the presence of a very low *Xipheroceras*; (4) the discovery (due to Dr. Spath) of the horizon of ammonites of the *A.-plotti* group; (5) the appearance of a *Sulciferites* [Spath] fauna at the lower Arietite horizon; (6) the finding of a new genus, *Pararnioceras* [Spath], containing many species, some new, and confined to the inch-thick bed 70c; and (7) the discovery of an abundant *Agassiceras* fauna below the *Pararnioceras* horizon.

My thanks are due to Mr. Robert Clark, of Lyme, who showed me the *brooki*-horizon; to Dr. L. F. Spath, who contributes Part II of this paper, for much help with the ammonites; to Mr. J. W. Tutcher for kindly lending me ammonites from the Bath–Radstock area, for comparison with the Charmouth forms; to Dr. A. E. Trueman for identifying some of the lamellibranchs; to Mr. W. A. Richardson (who contributes Part III) and to Mr. W. Campbell Smith, M.C., for help with the rocks and minerals; to Mr. A. Reeley for help in the field; lastly, to my wife, for constant help in the field and encouragement at home.

(B) Nomenclature of Rock-Forms.

Before considering in detail the Shales-with-Beef, it is desirable to explain the terms used in describing the rock-forms.

(1) Beef.—Fibrous calcium carbonate, always showing cone-in-cone structure, even if only on a microscopic scale. Seams of all thicknesses occur, from about 1/16 inch to some 4 inches. Generally speaking, the thicker the seam, the more obvious is the cone-in-cone structure; but it is possible to note conspicuous cone-in-cone structure in a very thin seam. Seams exceeding 2 inches in thickness, however, always show cone-in-cone structure clearly. All seams are double, and the cones of each layer interpenetrate at the junction. Naturally, such layers do not readily separate. Sometimes, however, one layer is very thin and, apparently, may temporarily thin out altogether. Further, such two-

[1] At my request, Mr. Tutcher very kindly sent to Dr. Spath these specimens for examination, as well as much *Agassiceras* material. Thanks to his prompt help, we have been able to compare the Dorset with the Bath–Radstock specimens.

[2] This is given in an addendum- and corrigendum-slip to Dr. A. Morley Davies's 'Introduction to Palæontology' 1920. On discovering the *Brooki*-Bed, I urged Dr. Davies to correct on the first opportunity the position of *A. brooki* as hitherto supposed and as given in his text-book; and this he did, as just stated. The exact position of the bed, however, and of the neighbouring sequence is here given for the first time.

layered seams from about 1/2 inch thick, and thicker, are themselves often double, each half being separated by a thin line of marl, and the cones of each half do not appreciably interpenetrate. Such fourfold seams readily separate at the middle, and white, crushed, and powdery remains of small ammonites often occur between the halves. The thin intervening film of marl may locally thicken into a lenticle of indurated and highly calcified marl, or even into a nodule of impure limestone, in which case the beef-seam appears in section to split and enwrap the nodule, which thus has an upper and a lower jacket of beef (75 a, *Birchi*-Nodular, and see 73 g, Pl. IV, fig. 2). In some cases (as, for example, 73 a, the lower nodule-bed of Reef 20), the lower layer of beef fails to enwrap the nodule, thinning out altogether on its sides. Sometimes, as in 74 a (Little Ledge), the large upper and lower beef, instead of enwrapping lenticles of calcified marl, enclose layer upon layer of beef with occasional filmy marl-partings. Sometimes beef more than 1/4 inch thick is seen to have replaced a small ammonite-shell. The ornament of the shell is then seen to appear on both the upper and the lower surfaces of the beef, showing that the beef takes up much more vertical room than the substance which it has replaced.

(2) Paper-shale, or laminated shale.—Brownish marl, poor in calcium carbonate, splitting along the bedding-planes into very thin, paper-like laminæ. The surface of each lamina is generally coated with granular crystals of selenite. Paper-shales appear to originate only as a product of weathering, since the farther that they are followed from the surface, the less is selenite present, and the less is the lamination developed.

(3) Bedded marl.—Bluish marl, which weathers along the bedding-planes; but if it splits into thin laminæ, like paper-shale, it does not, apparently, develop selenite between the laminæ, and is blue rather than brown.

(4) Conchoidal marl.—Pale bluish marl, weathering into larger or smaller conchoidal masses, instead of along the bedding-planes, which may, however, often be seen. It is paler than the bedded marl and, presumably, more calcareous; at any rate, more so than the paper-shale. It suggests (passing as it does into bedded marl, on the one hand, and into indurated marl, on the other) a beginning of segregation of calcium carbonate towards centres around which concentric lines of weakness develop, causing the marl to split into polygonal blocks with curved sides.

(5) Indurated marl.—As, for example, (71 a) Reef 18 and (72 a) Reef 19. An intermediate stage between conchoidal marl and tabular limestone. It is paler and harder than the former, softer than the latter, and weathers into conchoidal blocks.

(6) Tabular limestone.—A further calcification of an indurated marl, passing into it above and below. The core of (53)

Table Ledge is almost a tabular limestone; but the best examples are the typical limestones of the Blue Lias below. A tabular limestone may become lenticular or even nodular when followed laterally. The *Birchi*-tabular (76a) is a lenticular or semi-nodular tabular.

(7) Lenticles and nodules.—Lenticular and spherical masses of calcareous marl or impure limestone, generally showing bedding-planes. In the marls they usually pass by more or less rapid gradations into the surrounding marl; in the paper-shales they are generally separated from the surrounding shales by a jacket of beef. The *Brooki* Bed (74d) is a prominent exception to the last statement.

(8) Septarian nodules.—Nodules showing wide radial and concentric cracks, the sides of which are lined with crystalline calcite.

(9) Friable marl.—Impure blackish marl of a granular texture, hardly showing bedding, and breaking easily, crumblingly, and 'short,' much as shortbread does.

(10) Putty-marl.—Streaks, lenticles, and small nodules of very pale yellowish or pinkish marl, generally associated with friable marl, but sometimes with conchoidal marl.

(11) Short-rock.—An intimate mixture of coarse cone-in-cone beef and friable marl.

(12) Besides the rock-forms already enumerated, sulphide of iron occurs freely in the clays, generally in flat masses along bedding-planes, often on the upper and lower surfaces of a beef-seam, when it is generally much decomposed. Large clots of iron-sulphide occur in places on 76a, the *Birchi*-tabular. Calcite occurs in veins in the limestones. Selenite has already been mentioned; and barytes[1] is found in little, flat, circular discs with radial structure, in the marls of 71e (see p. 88). Finally, hydro-hæmatite[1] occurs, infilling the suture-line of a specimen of *Pararnioceras alcinoe* (Reynès), picked up in 1914 at the cliff-foot beneath the remains of the burning cliff of 1908.

(C) General Description.

Lithically, the Shales-with-Beef fall into two divisions. The upper division, some 30 feet thick, consists of paper-shales, is of a brown rather than blue colour, and has more numerous beef-seams than the lower division. Lenticles and nodules often have a jacket of beef. The lenticular (74d) *Brooki* Bed, however, although occurring in the upper division, has no beef associated with it. The paper-shales are capped by the *Birchi* Bed. This is a double limestone, the upper being more tabular than nodular, and the

[1] Determined by Mr. W. Campbell Smith, M.C., Sec.G.S.

lower consisting of large nodules (sometimes measuring 2×3 feet) surrounded by beef. The other limestones of this series are much thinner and, except the *Brooki* Bed, less persistent. The paper-shales are bounded beneath by (74 a) Little Ledge—a limestone made up entirely of many layers of beef and marl-films. It is very brittle, and for many yards at a time is fractured and faulted for an inch or so, at intervals of about a foot, while the beds on each side of it merely dip.

The lower division of the Shales-with-Beef, approximately 40 feet thick, and bounded below by (53) Table Ledge, and above by (74 a) Little Ledge, consists mainly of blue conchoidal marls, with occasional blue bedded marls, indurated marls, nodule-beds, friable marls, and impersistent beef-seams in the upper part; and in the lower part of similar beds with frequent seams of beef and short-rock. Throughout, impersistent beef-seams are often associated with friable marl. The nodules (except the beds 73 a & 73 g of Reef 20) are not enwrapped by beef.

Palæontologically, the Shales-with-Beef may be divided into three main divisions: namely, an upper (18 feet) corresponding to the range of *Microderoceras*; a middle division characterized by *Arietites*, *Sulciferites* [Spath], and *Arnioceras*, but no *Agassiceras*; and a lower division yielding *Arnioceras* and *Agassiceras*.

Only three beds of the upper division have yet yielded well-preserved fossils: namely, at the top, the *Birchi*-tabular, containing small specimens of *M. birchi* associated with *Xipheroceras* spp., *Cymbites* spp., and *Arietites turneri*; a foot below this the *Birchi*-nodular, containing large *Microderoceras birchi*, *Arietites plotti*, and allied forms[1]; and a little lenticle-bed, occurring 9 feet lower, containing *Cymbites* and *Arietites*, sp. nov.

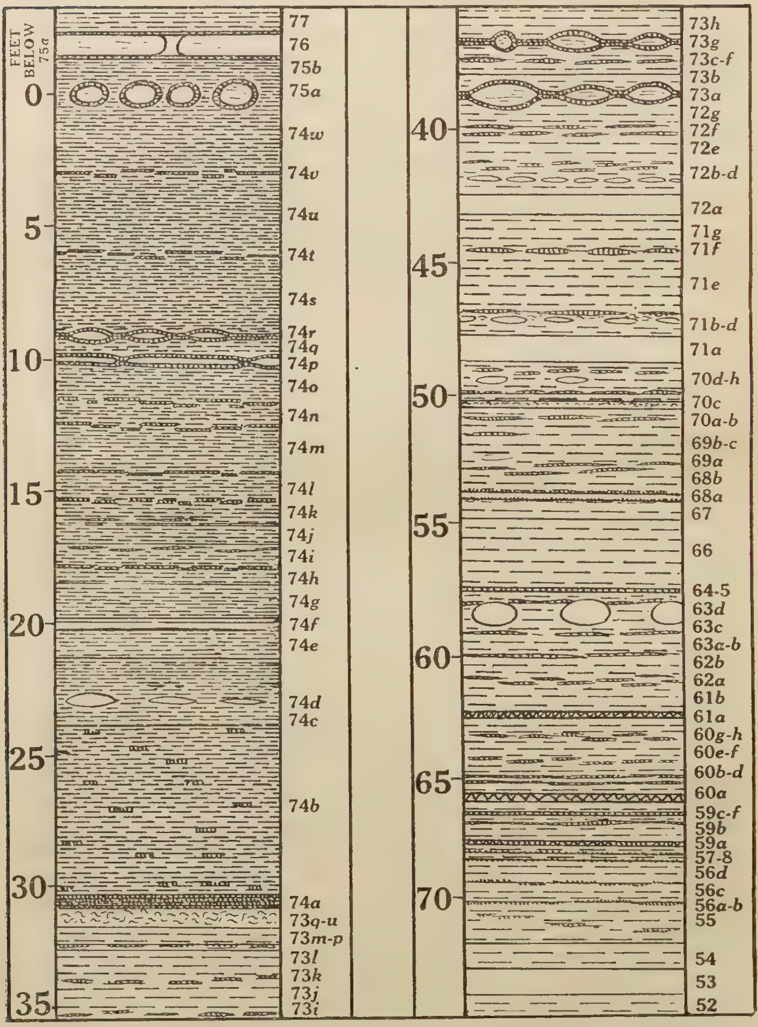
The topmost part of the middle division contains a limestone full of *Arnioceras hartmanni*, often black. Below this is the *Arietites-brooki* Bed, some 7 feet below which is a series of beds (about 8 feet thick) wherein *Arnioceras* is comparatively rare, but *Arietites* and *Sulciferites* [Spath] are abundant.

Sulciferites sulcifer, *S.* sp. cf. *dumortieri*, and *S.* sp. cf. *angustisulcatus* follow from above downwards, and associated with them are three new species of *Arietites*; but more collecting should be done before this sequence within the *Sulciferites* Beds can be considered proved. The lowest 11 feet of the middle division contain various species of *Arnioceras*, but no *Arietites* or *Sulciferites*; and this probably marks the lowest limit of Oppel's *A.-obtusus* Zone (see his 'Juraformation' 1856, p. 52).

The upper part of the lowest division yields *Agassiceras* but rarely, is characterized by many species of *Pararnioceras* [Spath], and contains abundant *Arnioceras*. It may be correlated with Oppel's '*tuberculatus*-Bett.' Below this are some 10 feet of marl yielding several forms of *Arnioceras* and *Agassiceras*, but no

[1] I have not yet found these *Arietites* of the *A.-plotti* group in place; but they occur (as noticed by Dr. Spath) on specimens associated with large *M. birchi*, and doubtless came from this horizon.

Fig. 2.—*Section of the lower part of the cliffs immediately west of Charmouth.*



Vertical scale: 1 foot=0·15 inch. *For 77 at the top of the third column, read '76 b,' and for 76, read '76 a.'*]

Agassiceras striaries. *A. striaries*, on the other hand, is found in the 11 feet of marls below this, in association with other species of *Agassiceras* and *Arnioceras*. The bottom 2 feet of the lowest division have not yielded *Agassiceras* (which, however, continues below the Shales-with-Beef), but contain a peculiar new species of *Arnioceras*. The three lowest horizons of the lower division correspond with the upper part of Oppel's '*Bucklandi*-Bett.'

The following scheme summarizes the divisions hitherto described [1]:—

(9) *Microderoceras* horizon. 21½ feet. 74 g–76 a. *Microderoceras birchi*, *Cymbites* spp., *Xipheroceras* spp., *Arietites turneri* at the extreme top. *Microderoceras birchi*, *Arietites plotti*, and allied forms a foot down.

(8) *Arnioceras-hartmanni* horizon. 5 feet. 74 e–74 f. *Arnioceras hartmanni*, *A.* cf. *hartmanni*, and *A.* cf. *patti* near the top.

(7) *Arietites-brooki* horizon. 1 foot. 74 c–74 d. *Arietites brooki*.

(6) *Sulciferites* [Spath] horizon. 13½ feet. 73 a–74 b. *Arnioceras* spp. common above, scarce below; *Arietites* three spp. nov., *Sulciferites* [Spath] *sulcifer*, *S.* cf. *dumortieri*, and *S.* cf. *angustisulcatus* in the lower part.

(5) Horizon with *Arnioceras* spp., but no *Arietites* or *Sulciferites*. 11¼ feet. 70 f–72 g.

(4) *Pararnioceras* horizon. 8 inches. 70 a–70 e. Abundant *Arnioceras* and *Pararnioceras* (70 c) of several species. *Agassiceras* occurs, if at all, but rarely.

(3) Horizon yielding *Arnioceras* and *Agassiceras* of various species, but not *Agassiceras striaries*. 1¼ feet. 62–69.

(2) Horizon with *Arnioceras* and *Agassiceras* of various species, including *A. striaries*. 11 feet 7 inches. 55–61.

(1) *Arnioceras* sp. nov. horizon. 2 feet. 53–54. No *Agassiceras*.

(D) Detailed Description (fig. 2, p. 56).

[Unless otherwise stated, the numbers after the name of a fossil are the register-numbers of specimens in Dr. W. D. Lang's collection. All such specimens will be transferred to the British Museum collection.]

76 b. Paper-shales with *Arietites* aff. *A. turneri*; 5287–97. *Microderoceras* sp.; 5269–70.

76 a. *Birchi*-tabular.[2] 1 foot. An irregular tabular to lenticular limestone, often with large clots of iron-sulphide sticking to its upper surface. *Microderoceras birchi*, small specimens; 5019–20, 5043–48, 4275–78. *Cymbites* cf. *semicostulatus*; 5021, *C. lævigatus*; 5022–27. *Xipheroceras* cf. *planicosta*; British Museum, C. 17971. *X.* cf. *capricornoides*; 5057–61. *Arietites turneri*; 5034–42, 5049–56.

75 b. 1 foot. Very fine paper-shales, with much decomposed iron-sulphide, also occasional and irregular impersistent beef-seams. *Ostrea* sp.; 930.

[1] The ammonite names here and in the following section have been written in the briefest manner possible, and can only be completely understood in conjunction with Part II, by Dr. L. F. Spath, where full references are given.

[2] For a photograph of the *Birchi*-tabular exhibiting a broken anticline on the foreshore at Mouth Rocks, Charmouth, see W. D. Lang, Proc. Geol. Assoc. vol. xxv (1914), pl. 40, fig. B.

75 a. *Birchi*-nodular.[1] 1 foot. Paper-shales, and very large nodules (sometimes as much as 3 feet long) with beef above and below. *Microderoceras birchi*, large specimens; 4953. *Arietites plotti*; British Museum, 50084. *A.*, sp. nov.; 2955, L. F. Spath colln. *A. pseudobonnardi* [Spath]; British Museum, C. 1891.

74 w. 3 feet. Paper-shales, with occasional irregular and impersistent beef-seams. *Microderoceras* sp.; 4513–58.

74 v. 3 inches. Thick beef-seam.

74 u. $2\frac{3}{4}$ feet. Paper-shales, with occasional irregular and impersistent beef-seams.

74 t. 2 inches. Beef, with much decomposed iron-sulphide.

74 s. 2 feet 10 inches. Paper-shales, with occasional irregular and impersistent beef-seams.

74 r. 1 inch (Pl. III, figs. 1 & 2). A double beef-band often enclosing lenticles. *Pholidophorus* sp. opercular (4431), and preopercular (4432 d). *Cymbites lævigatus*; 4423, 4425. *Microderoceras* sp.; 4424, 4426–28; 4430. *M.?*, sp. nov.; 4429. *Arietites*, sp. nov.; 4434.

74 q. 8 inches. Paper-shales, with occasional irregular and impersistent beef-seams.

74 p (Pl. III, figs. 1 & 2). 3 inches. Tabular to lenticular limestone, with beef.

74 o. 18 inches. Paper-shales, with occasional irregular and impersistent beef-seams, well-marked at the base. *Microderoceras* sp.; 4433.

74 n. 14 inches. Paper-shales, with occasional irregular and impersistent beef-seams, especially at the base.

74 m. 23 inches. Paper-shales, with occasional irregular and impersistent beef-seams, and at the base a line of beef with decomposed iron-sulphide above and below it. *Microderoceras* sp.; 4343–44.

74 l. 9 inches. Paper-shales, with occasional irregular and impersistent beef-seams, especially at the base.

74 k. 13 inches. Paper-shales, with occasional irregular and impersistent beef-seams. *Microderoceras* sp.; 4345.

74 j. 9 inches. Paper-shales, with occasional irregular and impersistent beef-seams, a layer of decomposed iron-sulphide at the base, and beneath this an irregular line of beef. *Microderoceras* sp.; 4346.

74 i. 11 inches. Paper-shales, with occasional irregular and impersistent beef-seams, and a band of beef below. *Microderoceras* sp.; 4347–48.

74 h. 6 inches. Paper-shales, with occasional irregular and impersistent beef-seams, and a layer of decomposed iron-sulphide at the base.

[1] For a photograph of a single nodule of the *Birchi*-nodular in place, showing the beef above and below, see *op. cit.* pl. 40, fig. A.

74 g. 17 inches. Paper-shales, with irregular and impersistent beef-seams. *Arietites* sp. cf. *plotti*; 5262–64, 5275–80. *Microderoceras* sp.; 5279.

74 f (Pl. IV, fig. 1). Black *Arnioceras* Bed, or *Hartmanni* Bed. 4 to 6 inches. Lenticular to tabular limestone, occasionally crowded with *Arnioceras*, at other points barren. *Arnioceras hartmanni*; 5073–91. *A.* cf. *hartmanni*; 5069–72, 5092–5105. *A.* cf. *patti* [horizon assumed from matrix]; 3237. *A.* cf. *nigrum*; 5106. ? *Cymbites* sp.; 5561.

74 e. 3 feet. Paper-shales, with many irregular and impersistent beef-seams. *Arnioceras* spp.; 4333–39.

74 d (Pl. IV, fig. 1). *Brooki* Bed. 0 to 3 inches. Lenticles. *Arietites brooki*, several variations; 4448–62, 4841, 4583 (large piece of a body-whorl of about 375 mm. diameter). *Cymbites lævigatus*; 4443–45. *Cymbites* sp., compressed form; 4442. *C.* aff. *globosus*; British Museum, C. 21924. ? *Avicula* sp.; 4436–41.

74 c (Pl. IV, fig. 1). 1 foot (with 74 d). Paper-shales, with many irregular and impersistent beef-seams. *Arietites* (?) spp.; 4368–69, 4522–24. ? *Arnioceras* sp.; 4525–26.

74 b (Pl. IV, fig. 1). 6 feet 4 inches. Paper-shales, with many irregular and impersistent beef-seams. *Arnioceras* sp.; 4370–73, 4527–32.

74 a. Little Ledge. 6 inches. Manifold beef-seam, with very thin marly partings. *Ichthyosaurus* sp., caudal vertebra; 2810. *Ostrea* sp.; 4034–35. *Arnioceras* sp.; 4293, 4533.

73 u. 1 inch. Bedded marl, with occasional beef at the base.

73 t. 1½ inches. Friable marl.

73 s. ½ inch. *Arnioceras* Bed in friable marl. *Arnioceras* sp. cf. *semicostatum*; 4392, 4574.

73 r. 4 inches. Friable marl.

73 q. 2 inches. Passage from fine conchoidal marl to friable marl. *Arietites* sp.; 4559.

73 p. 7½ inches. Fine conchoidal marl. *Arietites*, sp. nov.; 4308. *Arietites*, sp. nov.; 4307. *A.*, sp. nov.; 2790, 2795 (associated with *Sulciferites sulcifer* and provisionally placed in this bed). *S.* [Spath] *sulcifer*; 4402, 4560–61.

73 o. ½ inch. Persistent beef-seam.

73 n. 1½ inches. Fine conchoidal marl.

73 m. ½ inch. Iron-sulphide. *Sulciferites* [Spath] sp.; 4562.

73 l. 14 inches. Fine conchoidal marl. *Arnioceras* sp. cf. *semicostatum*; 4563–66. *Sulciferites* [Spath] *sulcifer*; 4567–69. *Sulciferites* [Spath] sp. cf. *dumortieri*; 4310–16. *Plagiostoma* sp.; 4322.

73 k. 1 inch. Thin impersistent beef-seams.

73 j. 14 inches. Fine conchoidal marl. *Arnioceras* sp. cf. *semicostatum*; 4413. ? *Arietites* sp.; 4570, 4414. *Sulciferites* [Spath] sp. cf. *dumortieri*; 4584–85.

73 i. 1 inch. Thin impersistent beef-seams.

73 h. 13 inches. Fine conchoidal marl. *Arietites*, sp. nov.; 4309, 4591. *Sulciferites* [Spath] sp. cf. *angustisulcatus*; 4586–90.

73 g (Pl. IV, fig. 2). Reef 20, upper limit. 2 inches. Persistent, double to manifold beef-seam, occasionally enclosing lenticles and nodules. The upper surface of this bed, of which a rather wide expanse is often visible at the shoreward end of the Reef, presents rough irregular ridges radiating from centres, resembling in appearance the stools of fossil trees.

73 f. Slabby, slightly conchoidal marl. *Sulciferites* [Spath] sp. cf. *angustisulcatus*; 4600–6.

73 e. 1 inch. Beef.

73 d. 7 inches. Slabby, slightly conchoidal marl. *Arietites* sp.; 4607–8.

73 c. ½ inch. Iron-sulphide in little crystalline clots. *Arietites* sp. nov.; 4609.

73 b. 6½ inches. Slabby, slightly conchoidal marl.

73 a (Pl. IV, fig. 2). Reef 20, lower limit 2 inches. Double to manifold beef-seam, occasionally enclosing lenticles and nodules.

72 g. 17 inches. Slabby, slightly conchoidal marl. *Arnioceras* sp. cf. *semicostatum* and *A.* sp. cf. *nodulosum*; 4610–17. *Avicula* sp. near *A. infraliasina* (Martin); 4619. ? *Avicula* sp.; 4618. *Rhynchonella* sp.; 4620–24.

72 f. 2 inches. Impersistent beef-seams in friable marl. *Arnioceras* sp. cf. *nodulosum*; 4625. *Belemnites* sp.; 4962. ? *Avicula* sp.; 4626.

72 e. 13 inches. Bedded marl. *Arnioceras* sp. cf. *nodulosum*; 4627–32. *Arnioceras* sp. cf. *semicostatum* and *nodulosum*; 4383. ? *Avicula* sp.; 4389–90.

72 d. 6 inches. Impersistent beef-seams in friable marl.

72 c. 1 inch. Small lenticles in conchoidal marl. *Arnioceras* sp.; 4288.

72 b. 4 inches. Conchoidal marl, passing into 72 a.

72 a (Pl. IV, fig. 2). Reef 19. 10 inches. Indurated marl full of *Avicula*. *Arnioceras* sp. cf. *semicostatum*; 863, 865, 869, 2759–66, 2778–80, 3204, 4418–20. *Arnioceras* sp. cf. *falcaries*; 2783. *Arnioceras* sp.; 2781–82. *Belemnites* sp.; 4295. *Plagiostoma giganteum* James Sowerby; 2767. *Avicula* sp. cf. *A. inæquivalvis* James Sowerby; 857–862, 864, 866–68, 870, 2748–50, 2755–57, 2751–53, 4294, 4421. *Avicula* cf. *A. papyria* Quenstedt; 3203.

71 g. 20 inches. Slabby, slightly conchoidal marl. *Arnioceras* sp. cf. *semicostatum*; 4633–36. *Arnioceras* sp. =

A. ceratitoides Quenstedt ('Ammoniten des Schwäbischen Jura' 1883, pl. xiii, fig. 7 only); 2633.

71 f. 1 inch. Impersistent beef.

71 e. 28 inches. Bedded marl, with occasional small, flat, circular discs of barytes, exhibiting radial structure. *Arnioceras* sp. cf. *semicostatum*; 4637–42.

71 d. 1 inch. Impersistent beef.

71 c. 1 inch. Friable marl.

71 b. 6 inches. Small lenticles in limy conchoidal marl, passing into 71 a.

71 a. Reef 18. 1 foot. Indurated marl. *Arnioceras* sp. cf. *semicostatum*; 4358, 4643, 4359–65. *Arnioceras* sp. cf. *nigrum*; 4645. *Arnioceras* sp.; 4287. *Belemnites* sp.; 4945. ? *Avicula* sp.; 4366. *Avicula* sp.; 4646. *Ichthyosaurus* sp., coprolites; 4036.

70 h. 6 inches. Conchoidal marl. *Arnioceras* sp. cf. *nodulosum*; 4647. ? *Avicula* sp.; 4648.

70 g. 3 inches. Irregular beef.

70 f. 8 inches. Small lenticles in conchoidal marl.

70 e. 1 inch. Beef.

70 d. 2 inches. Conchoidal marl.

70 c. *Pararnioceras-alcinoe* Bed. 1 inch. Friable marl and putty-marl. Beds from 69 b to 70 c can be traced (though poorly shown) eastwards of Reef 14 and as far as the fault immediately west of Reef 15 (see fig. 1, p. 50). Large *Pararnioceras alcinoe* may be found in and obtained from 70 c, on the reefs immediately east of Reef 17, by pulling at the plants of *Fucus*. Where several of these are growing on the surface of a large *P. alcinoe*, big pieces of the fossil come away with the seaweed still attached thereto. *Arnioceras* sp. cf. *bodleyi*; 2796, 4027, 4234–36a, 4651, 4653–54. *Arnioceras* sp. cf. *ceratitoides*; 2562. *Arnioceras* sp. cf. *mendax* var. *rariplicata*; 2564, 2598–99. *Arnioceras* sp. cf. *speciosum*; 2563, 2784, 4655–57. *Arnioceras* sp.? cf. *miserabile* auctt., *non* Quenstedt; 2785. *Arnioceras* spp.; 2564, 2568, 4232–33. *Pararnioceras alcinoe*; 2600, 2590, 3982–83, 4242–43, 2713, 4412, 4519, 4652. *Pararnioceras* sp. aff. *alcinoe*; 4241, 4521, 5398. *Pararnioceras* sp. nov. aff. *alcinoe*; 4853, 3980. *Pararnioceras* sp. aff. *compressaries* Quenstedt, pars; 2615, 4238–40. *Pararnioceras* sp. nov.; 3981, 4520. *Pararnioceras* sp. cf. *breoni*; 4649. *Pararnioceras* spp.; 2572, 4026, 4028, 5397. ? *Agassiceras* sp. cf. *terquemi*; 4029. ? *Agassiceras* sp. cf. *reynesi* Spath; 4236. *Nautilus* sp.; 4658. *Belemnites acutus* Phillips *non* Miller; 4040, 4025, 4032, 4659–63. *Ostrea* sp.; 2797. *Gryphæa* sp. cf. *G. arcuata* Dumortier (*non* Lamarck), 1864, 'Études Pal. . . . Bassin du Rhône' vol. i, p. 83 & pl. xiii, figs. 4–5

only; 4244. *Pecten* sp.; 2797. *Pecten* sp. cf. *P. æqualis* Quenstedt; 4022–23. *Pecten* sp. cf. *P. textorius* Schlotheim; 4464. ? *Pleuromya* sp.; 2607. *Spiriferina* sp. cf. *S. walcotti* (J. de C. Sowerby); British Museum, B. 41480. *Isocrinus* sp. cf. *tuberculatus* (Miller); 4033. Diademoid-spine; 4031. Fish-remains; 4939.

70 b. 4 inches. Conchoidal marl. *Arnioceras* sp. cf. *speciosum*; 4024.

70 a. Reef 17. 2 inches. Beef, with a little friable marl below. *Arnioceras* sp. cf. *ceratitoides*; 4237.

69 c. 8 inches. Fine conchoidal marl. *Arnioceras* sp.; 4669.

69 b. 19 inches. Fine conchoidal marl, with occasional putty-marl, passing into bedded marl; occasional beef at the top. *Arnioceras* sp. cf. *ceratitoides*; 2576, 4671. *Arnioceras* sp. cf. *obliquecostatum*; 4670. *Arnioceras* sp. cf. *geometricum (?)*; 3156. *Arnioceras* sp.; 3157–67, 4672. *Agassiceras* sp. cf. *sauzeanum*; 4673. *Plagiostoma* sp.; 3172–76. ? *Avicula* near *A. infraliasina* (Martin); 3191. ? *Avicula* sp.; 3192–99.

69 a. Reef 14, repeated by the easternmost fault as Reef 16. 2 inches. Beef in friable marl. *Arnioceras* sp. cf. *speciosum*; 3148–49. *Arnioceras* sp. cf. *obliquecostatum*; 3150–51, 3154. *Arnioceras* sp. cf. *insigne* Fucini; 4020. *Belemnites acutus* Phillips, *non* Miller; 4509–11. *Ostrea* sp.; 3178. ? *Avicula* sp.; 3179–81. ? *Rhynchonella* sp.; 3177. *Ichthyosaurus* sp., vertebra; 4417.

68 b. 7 inches. Fine conchoidal marl. *Arnioceras* sp. cf. *obliquecostatum*; 4341. *Arnioceras* sp. cf. *nodulosum*; 3124. *Arnioceras* sp. ? cf. *dimorphum*; 4674. *Arnioceras* spp.; 3118–21, 3123. *Agassiceras* sp. cf. *sauzeanum*; 3122. *Belemnites acutus* Phillips, *non* Miller; 4508. *Plagiostoma* sp.; 3132. *Avicula* sp. cf. *A. inequivalvis* James Sowerby; 3137–38, 3140. *Avicula* sp.; 3136, 3139. ? *Gervillia* sp. of the pattern of *G. obliqua* Martin; 4676. ? *Gervillia* sp.; 3134–35, 3141–45.

68 a. Reef 13, repeated, as Reef 15, by the easternmost of the three faults described below (under 64), that having a downthrow of 2 feet on the west. 2 inches. Beef in friable marl.

67. 8 inches. Fine, pale conchoidal marl.

66. 3 feet. Fine conchoidal to bedded marl. *Arnioceras* sp.; 4677, 4679. *Agassiceras* sp. cf. *sauzeanum*; 4678, 4680–82.

65. Reef 9, repeated as Reefs 11 & 12 (Reef 11 is the seaward continuation of 12, separated from it by a channel). 1 inch. Beef and friable marl. *Arnioceras* sp.; 4395, 4683. *Belemnites* sp.; 4984. *Avicula* sp.; 4397. ? *Avicula* sp.; 4684. *Dapedius* sp.; 4396.

64. 3 inches. Fine conchoidal marl, with beef and occasional very large nodules, which are as much as 1 foot thick vertically, and invade 63 d. They are rather rare on the cliff-section, and consequently this horizon is not so easily detected there as might be expected from an examination of the reefs. But their presence in the cliff-section is valuable evidence for correlation with the reefs; and on the reefs, where they are fairly plentiful, the nodules occur twice (see fig. 1, p. 50), indicating the repetition caused by the middle of the three little faults in the Shales-with-Beef at this part of the coast. This middle fault has a downthrow of about 8 feet on the west. *Arnioceras* sp. cf. *obliquecostatum*; 3096. *Arnioceras* sp. cf. *turneri* (J. Sowerby, lower figure); 3100–1. *Arnioceras* sp.; 3094. *Agassiceras* sp. cf. *spinaries*; 4687–90, 4692–98. *Agassiceras* sp.; 4400. *Belemnites acutus* Phillips, *non* Miller; 4685–86. *Plagiostoma* sp.; 3102–3. *Avicula* sp. cf. *A. inæquivalvis* James Sowerby; 3097–99. ? *Gervillia* sp.; 3108–13. *Ostrea* sp.; 3107. *Rhynchonella* sp.; 3104–6. *Ichthyosaurus* sp., vertebra; 4416.

63 d. 11 inches. Fine conchoidal marl. *Belemnites acutus* Phillips, *non* Miller; 4701. *Belemnites* sp.; 4700. *Rhynchonella* sp.; 4699.

63 c. 1 inch. Strings of beef in friable marl.

63 b. 1 foot. Fine conchoidal marl. *Agassiceras* sp. cf. *gaudryi* (Reynès); 4702. *Agassiceras* sp. cf. *spinaries*; 4703–4.

63 a. 1 inch. Beef-seam.

62 b. 10 inches. Fine conchoidal marl to bedded marl. *Agassiceras* sp.; 4705 a. *Avicula* sp.; 4705 b.

62 a. 3 inches. Strings of beef in marl.

61 b. 14 inches. Fine conchoidal marl.

61 a. Reef 8, repeated as Reef 10. 2 inches. 'Short-rock.' Makes a distinct line near the base of the cliff beneath Black Ven. *Arnioceras* sp. cf. *anomaliferum*; 3070–76. *A.* sp. cf. *obliquecostatum*; 3069. *Agassiceras* sp. cf. *spinaries*; 2812. *Plagiostoma giganteum* James Sowerby (small specimens); 3077–86. *Avicula* sp.; 3087–88. ? *Avicula* sp.; 3090–92. *Ostrea* sp. cf. pattern of *O. irregularis* Münster; 3090. *Gryphæa* sp., of a form near *G. sublamellosa* (Dunker) in Dumortier, 1864, 'Études Pal.... Bassin du Rhône' vol. i, p. 79 & pl. vii, figs. 12–13 only; 3089.

60 h. 8 inches. Fine conchoidal to bedded marl. *Arnioceras* sp.? cf. *falcaries*; 4351. *Arnioceras* spp.; 4352–57, 4719–22. *Plagiostoma* sp.; 4350. ? *Avicula* sp.; 4349.

60 g. 2 inches. Beef-strings in marl. *Arnioceras* sp.; 4706. ? *Avicula* sp.; 4707. *Ichthyosaurus* sp., large specimen, the anterior end of which is still in the cliff.

60 f. 9 inches. Fine conchoidal to bedded marl. *Arnioceras* sp. cf. *nodulosum*; 4726, 4735. *A.* sp. cf. *obliquecostatum*; 4712–13, 4716. *A.* sp. cf. *arnouldi*; 4723–53. *Arnioceras* sp.; 4708, 4711, 4714–15, 4727–29, 4731–34. *Agassiceras* sp.; 4709, 4710, 4842. ? *Avicula* sp.; 4717–18.

60 e. 2 inches. Beef-strings in marl. *Arnioceras* spp.; 4323–31, 4382. *Lima* sp.; 4332.

60 d. 8 inches. Fine conchoidal to bedded marl. *Arnioceras* sp.? cf. *anomaliferum*; 4745, 4747–51. *A.* sp.? cf. *falcaries*; 4746. *Agassiceras* sp. cf. *striaries*; 4742, 4744. *A. sauzeanum*; 4743. *Plagiostoma* sp.; 4737. ? *Avicula* sp.; 4736, 4738–41.

60 c. 2 inches. A double layer of 'short-rock,' separated by fine conchoidal marl.

60 b. 5 inches. Fine conchoidal marl. *Agassiceras* sp.; 4375–79, 4752. ? *Avicula* sp.; 4380. Brachiopod, 4381.

60 a. Reef 7. 3 inches. 'Short-rock.' A very conspicuous reef, forming a distinct line near the base of the cliff beneath Black Ven. *Arnioceras* sp. cf. *obliquecostatum*; 2793, 3061–62, 3064–66. *A.* sp. cf. *arnouldi*; 3063. *A.* sp. cf. *speciosum*; 2792. *Agassiceras spinaries*; 4401. *Plagiostoma* sp.; 3067. *Ostrea* sp., encrusting ammonite; 3068.

59 f. 6 inches. Fine conchoidal marl. *Belemnites acutus* Phillips, *non* Miller; 4754.

59 e. 1 inch. Beef. *Arnioceras* sp. cf. *obliquecostatum*; 4394. *A.* sp.? cf. *arnouldi*; 4393.

59 d. 4½ inches. Very fine, rather dark, conchoidal marl.

59 c. ½ inch. Beef.

59 b. 10 inches. Very fine, dark, conchoidal marl. *Arnioceras* sp. cf. *obliquecostatum*; 4754. *Agassiceras* sp.; 4755.

59 a. Reef 6. 2 inches. Very pale calcareous marl, with some friable marl and putty-marl. Conspicuous at the cliff-foot beneath Black Ven. *Arnioceras* sp. cf. *obliquecostatum*; 3045, 3049. *A.* sp. cf. '*mendax* var. *rariplicata*'; 3047. *Arnioceras* sp.; 3046. *Agassiceras spinaries*; 4756–59. *Avicula* sp.; 3051–54. *Plagiostoma punctatum* James Sowerby; 4769–70, 4768, 4771, 3055. *Ostrea* sp.; 4760–65. ? *Avicula* sp.; 3058–60. *Rhynchonella* sp.; 4766–67. *Myriacanthus* sp.; 3044.

58 b. 6 inches. Fine conchoidal marl. *Arnioceras* sp.; 4772.

58 a. Reef 5. 1 inch. Beef and marl. *Arnioceras* sp. cf. *obliquecostatum*; 3040–42. *Arnioceras* sp.; 3038–39.

57 b. 2 inches. Fine conchoidal marl. *Arnioceras* sp. cf. *obliquecostatum*; 4374. *Arnioceras* sp.; 4773–74, 4776. *Agassiceras* sp. cf. *striaries*; 4775. *Plagiostoma* sp. 4777–78. ? *Avicula* sp.; 4779–81. *Avicula* sp.; 3037. *Ostrea* sp., encrusting ammonite; 3035.

57 a. Reef 4. 1 inch. Beef and marl. At the cliff-foot beneath Black Ven.

56 d. 1 foot. Fine conchoidal marl. *Arnioceras* sp.; 4783 a. *Agassiceras* sp. cf. *striaries*; 4787–88. *Agassiceras* sp. cf. *sauzeanum*; 4785–86. *Agassiceras* sp.; 4783 b, 4782, 4784. *Avicula* sp.; 4789. *A.* sp. cf. *A. inæquivalvis* James Sowerby; 3021.

56 c. 9 inches. Fine conchoidal marl, with a line of beef above. *Arnioceras* sp. cf. *geometricum?*; 4790–93, 4795. *Agassiceras* sp. cf. *striaries*; 4826. *Agassiceras* sp. cf. *sauzeanum*; 4825. *Agassiceras* sp.; 4794, 4796. *Plagiostoma* sp.; 4823. *Avicula* sp. cf. *A. inæquivalvis* James Sowerby; 4822. *Avicula* sp.; 4824. *Eugnathus* sp.; 4828.

56 b. Reef 3. 3 inches. Slabby conchoidal marl above beef. *Agassiceras striaries*; 4797–4806. *Agassiceras* sp. cf. *spinaries*; 4814–15. *A.* sp. cf. *spinaries* more closely costate; 4807–10. *Agassiceras sauzeanum*; 4398–99, 5260–61. *Agassiceras* sp. cf. *sauzeanum*, more compressed; 4811–13. *Plagiostoma* sp., near *P. duplicatum* J. de C. Sowerby; 4816.

56 a. 6 inches. Pale conchoidal marl, with occasional lumps and streaks of putty-marl. On the foreshore beneath Black Ven. *Agassiceras* sp. cf. *striaries*; 4818. ? *Avicula* sp.; 4819–20.

55. Reef 2. 6 inches. Conchoidal marl, with impersistent beef-seams. *Arnioceras* sp.; 3007. *Ostrea* sp., encrusting ammonites; 3000–6, 1125. *Avicula* sp.; 3011–13. *Rhynchonella* sp.; 3008–10.

54. Reef 1. 1 foot. Conchoidal marl, passing below into the indurated marl of 53. *Arnioceras* sp.; 2991. *Ostrea* sp., encrusting ammonites; 1072, 2922–27. *Rhynchonella* sp.; 2982–90.

53. Table Ledge. 1 foot. Tabular limestone, passing above and below through indurated marl into conchoidal marl. Forms a wide expanse on the foreshore below Black Ven. Huddles of *Rhynchonella* stand out as lumps from the surface. *Arnioceras* sp. nov.; 2715, 2740, 2742, 2744, and British Museum, C. 23519. *A.* aff. eidem sp. nov.; 4013–15. *Avicula* sp. cf. *A. inæquivalvis* James Sowerby; 2747, 2738, 1112–15. *Avicula* sp.; 629, 2739. ? *Avicula* sp. (black form); 622, 4016, 1210–13, 2719–24, 2734–36, 2805–7. ? *Avicula* sp.; 2725, 2737, 2808. *Plagiostoma punctatum* James Sowerby; 2746. *Plagiostoma* sp.; 4410. *Ostrea* sp.; 2977–78. *Ostrea* sp. (encrusting ammonites); 4411, 4012, 5254–56. *Rhynchonella* sp.; 1069, 2727–31, 2745, 4007.

52. Conchoidal marl. *Agassiceras* sp. cf. *spinaries*; 4405–7, 4836; at 2 feet below 53.

EXPLANATION OF PLATES III & IV.

Plate III.

Fig. 1. The upper 18 feet of Shales-with-Beef, on the west side of Charmouth beach. They are paper-shales, with numerous seams of beef (showing white in the photograph) and occasional lenticles of limestone. The beds are thrown into gentle folds as they approach the fault in the Char valley, situated less than 100 yards east of the photograph.

The lowest bed seen is 74 i. The beef separating 74 j and 74 k passes behind the child's head. Just above the child's head is the beef between 74 k and 74 l, while that between 74 l and 74 m lies immediately above this. 74 m is a wide bed, and the beef separating 74 m from 74 n is very conspicuous low down on the right of the photograph. Near the middle of the cliff, and nearly at the top of the clearly-exposed section, the irregular limestone 74 p and the lenticle-bed 74 r stand out clearly. The upper part of the cliff is largely grassed-over, but a piece of the *Birchi*-tabular (76) is visible to the right of the middle line of the photograph and nearly at the cliff-top.

2. A nearer view of some of the same beds, from a little to the east of those shown in fig. 1. The bottom of the section is in 74 n. The hammer lies across an impersistent beef-seam in the middle of 74 o. A little way above the hammer is the nodule-bed (74 p), shown clearly only in the middle of the photograph. The lenticle-bed (74 r) stands out very clearly above 74 p.

Plate IV.

Fig. 1. Paper-shales in the Shales-with-Beef, from 20 to nearly 30 feet below the *Birchi*-nodular. The conspicuous bed near the top of the photograph is the Black *Arnioceras* Limestone (*Hartmanni* Bed), 74 f. Immediately to the left of the middle of the photograph is a hole whence shales have been dug. On a level with the top of the hole is the *Brooki* Bed (74 d), one lenticle of which may be seen in place towards the right of the photograph, and the hole resulting from pulling out another lenticle lies at the same level to the right of the big hole. The thick beef-seam at the base of the section lies but a foot or so above Little Ledge (74 a).

2. A section in the Shales-with-Beef, from about 35 to 43 feet below the *Birchi*-nodular. The indurated marl at the base is 72 a, Reef 19. The beef-seam (bed 72 f) passes behind the child's neck. The strong beef-seam above this is 73 a, the lower limit of Reef 20, and the big lenticle in the middle of the photograph is in bed 73 f, the upper limit of Reef 20. Between 73 a and 73 f can be seen, below, the iron-sulphide band (73 c), and, above, the beef-seam (73 e). The beds from 73 c to the top of the section are in the lower Arietite horizon, and contain, too, *Sulciferites*.

Part II. Palæontology: the Ammonites of the Shales-with-'Beef.' (By L. F. S.)

(A) Introduction.

A list of the species of ammonites, identified by me, has already been included in Dr. Lang's stratigraphical account. It is intended here to review and amplify these identifications, and to attempt to justify the generic classification which I have adopted, also to

Fig. 1.—*Upper 18 feet of the Shales-with-Beef:* Microderoceras *horizon.*

Fig. 2.—*Nearer view of the same beds, taken a little farther east.*

Fig. 1.—*Shales-with-Beef*: brooki *and* hartmanni *horizons.*

Fig. 2.—*Shales-with-Beef: Beds 72 and 73, including the horizon of* Sulciferites.

discuss the phylogenetic relations of some of the ammonites of the Lower Lias. The development of a number of important types here dealt with, for instance, *Arnioceras*, *Agassiceras*, *Arietites*, *Cymbites*, *Xipheroceras*, *Microderoceras*, etc., was studied some years ago; but only brief reference can be made to this ontogenetic work, and it is also impossible at present to figure the new forms here recorded. It is a matter for regret that, in the absence of detailed stratigraphical work and careful zonal collecting for other districts, exact correlation is as yet impossible; and, for this reason, but little help was obtained from a study of the splendid collections in the British Museum (Natural History), of the genus *Arnioceras*, from Yorkshire and the Midlands, for instance. On the other hand, my *Arnioceras* material from Skye, described separately,[1] proved of use, and confirmed what, so long ago as Dumortier's time, was surmised of the enormous range of this genus, although sufficient emphasis had not been laid upon it in previous accounts of the Dorset succession. Also, a collection made by the late Sir Henry Butlin, and recently presented to the British Museum (Natural History), contains a number of ammonites from Stockton in Warwickshire; and, since some of them were collected in place and their occurrence was carefully noted, it has been possible to obtain from them additional valuable information.

Unfortunately, the preservation of most of the ammonites in the Shales-with-Beef is bad, and many species of *Arnioceras*, as, for example, '*A. obliquecostatum*,' are based only on the character of the ribbing on the outer whorls, obviously a most unsatisfactory criterion. The same remark applies to '*Arnioceras mendax*, var. *rariplicata*' Fucini. A specimen collected at Redcar, not *in situ*, but associated with '*Ammonites*' cf. *latesulcatus* Quenstedt, and *Arnioceras* cf. *arnouldi* (Dumortier), which probably come from below the *gmuendense* subzone, also agrees externally with the Italian form: the suture-line, however, is quite different, for, while the suture-line of the Italian species resembles that of the Gloucestershire *A. nodulosum* (J. Buckman), that of the Redcar specimen agrees with the suture-lines of *A. hartmanni* (Oppel), as here interpreted, *A. semicostatum* (Young & Bird) and *A. nigrum* (Blake), all late forms. The resemblance based on ribbing is probably quite accidental, hence the difficulty of naming the badly-preserved Dorset specimens here dealt with. Another crushed form, from bed 70, was at first identified as *Ætomoceras scipionianum* (A. d'Orbigny), and, being associated with many large '*Coroniceras*', suggested a horizon far too low in the sequence. But *Agassiceras* proved to be common in the strata below, so that it was clear that bed 70 must be above and not below Mr. Tutcher's *sauzeanum* zone or horizon I of the Harzburg Ironstone. The '*Ætomoceras*' just mentioned is thus probably a laterally-flattened crushed *Agassiceras*, comparable to Reynès's[2] *Ammonites multicostatus* Sowerby, var. *spinaries*

[1] 'On Lower Lias Ammonites from Skye' Geol. Mag. 1922, pp. 170–76.
[2] 'Monographie des Ammonites' 1879, pl. xxiv, fig. 25.

Quenstedt, or C. F. Parona's[1] *Agassiceras nodosaries* (Quenstedt), of equally doubtful preservation. There is, then, no trace of *Ætomoceras* in these beds. Similarly, there is no true *Agassiceras* in the *scipionianum* beds of Broadford in Skye, but only the more or less homœomorphous *Ætomoceras* development mentioned below.

Little importance, therefore, can be attached to individual identifications ; but the association of forms is, in my opinion at least, of the greatest significance. If it were not for the fact that it might give rise to serious misidentifications, I would even prefer J. F. Blake's[2] or E. Haug's[3] uniting of *Ammonites* [*Ætomoceras*] *personatus* Simpson, with *A. scipionianus*, to Buckman's[4] relegation of it to *Agassiceras*, which latter genus develops similar forms at a later date. Biological speculations in palæontology, if not based on careful collecting, are generally useless. In fact, it appears from the present discoveries that in A. Hyatt's subseries, for instance, containing *A. hartmanni*,[5] the 'degenerate' form is the earlier, and the 'anagenetic' one is the later in origin, thus showing that the development of ammonites is not always in accordance with the current 'laws.'

(B) Genus *Arnioceras* Hyatt.

This genus is the one that is most abundantly represented in the Shales-with-Beef. It ranges from beds beneath the lowest horizon here dealt with up to the Black *Arnioceras* Limestone (=*hartmanni*-bed, 74 f), that is to say, there are some 53 feet of *Arnioceras*-bearing strata in the 'Shales-with-Beef' alone, not including beds below (53) Table Ledge, where a number of earlier series of *Arnioceras* are expected to occur.

Now *Arnioceras ceras* (Giebel) Hauer sp., generally taken to be a typical *Arnioceras*, is one of these early forms, and close to *A. geometricum* (Oppel) and *A. ceratitoides* (Quenstedt) Schmidt, which species are associated in the Harzburg Ironstone[6] with '*Coroniceras*' belonging to beds below the *gmuendense* subzone. To judge by the results of my collecting in Skye, the '*Arnioceras*' of the *gmuendense* and those of the *scipionianum* subzones are different, both from the *Arnioceras* of the beds below and from '*Eparnioceras*' of the *semicostatum* type above. For *A. kridion*

[1] 'Contribuzione alla Conoscenza delle Ammoniti Liasiche di Lombardia, pt. iii: Ammoniti del Calcare Nero di Moltrasio, &c.' Mém. Soc. Pal. Suisse, vol. xxv (1898) pl. xv, figs. 1 & 2.

[2] R. Tate & J. F. Blake, 'The Yorkshire Lias' 1876, p. 287.

[3] 'Ueber die Polymorphidæ, eine neue Ammonitenfamilie aus dem Lias' Neues Jahrb. vol. ii (1887), p. 97.

[4] 'Yorkshire Type-Ammonites' vol. iii (1920) p. xxiv & pl. clxxxvii.

[5] 'Genesis of the Arietidæ' Smithson. Contrib. 673 (1889) Summary, pl. xii [vol. xxvi, 1890].

[6] E. W. Schmidt, 'Die Arieten des Unteren Lias von Harzburg,' in J. F. Pompeckj, 'Beiträge zur Paläontologie & Stratigraphie des Nordwestdeutschen Jura' Palæontographica, vol. lxi (1914) p. 4.

Hehl in Zieten, generally included in *Arnioceras*, the genus *Arnioceratoides* was proposed, this development being more nearly allied to *Coroniceras*; but with only the material that is at present at my disposal, the separation of what here are called true *Arnioceras* from '*Eparnioceras*' is practically impossible, and so they are all left in *Arnioceras* sensu lato.

Unfortunately, Mr. Buckman[1] in 1911 chose as genolectotype of *Arnioceras* a form (*A. ceratitoides* Agassiz=*A. ceras* in Hyatt, 'Genesis of the Arietidæ' pl. ii, fig. 20) that has nothing to do with the true *A. ceras* (Giebel) Hauer (1856) or the earlier (1849) *A. ceratitoides* Quenstedt, which probably is a badly-figured example of the same common Adneth form. The suture-line of the misidentified form of Hyatt agrees neither with that of the early *Arnioceras ceras*, nor with that of typical '*Eparnioceras*'; moreover, Hyatt's error had been detected already in 1902 by A. Fucini,[2] who included Hyatt's form in Parona's *A. dimorphum*, although coiling and suture-line differ considerably. The numerous species of the large (probably polyphyletic) genus *Arnioceras*, require revision; but a point that may here be made is that, until corrected by the collector, the palæontologist considered *Arnioceras* to be one of the most easily- and safely-determinable genera of ammonites, and the reference of, for example, the early *Arnioceras acuticarinatum* (Simpson) to the late *semicostatum* zone seemed natural. Another important point is that the dissimilarity of the *Arnioceras* faunas or, rather, of the common museum-specimens of *Arnioceras*, from Dorset to Yorkshire, is due to differences in their dates of existence, and probably not to differences in geographical distribution; and it is the great merit of Mr. S. S. Buckman to have been the first to drive home this lesson of dissimilar faunas.

The range of *Arnioceras*, however, through the 53 feet of deposits here mentioned is not uninterrupted, and from several horizons (for instance, 62 & 63) no example of *Arnioceras* has yet been found, although the absence is doubtless due only to collection-failure. On the other hand, the *brooki* nodules (74 d) are crowded with *Arietites* and *Cymbites*, but no *Arnioceras* occurs in them; whereas in the following horizons (74 e & 74 f) *Arnioceras* is again the dominant genus.

This last horizon, the Black *Arnioceras* Bed (74 f) is here denominated the horizon of *A. hartmanni* (Oppel). Owing to the fact, however, that A. d'Orbigny's[3] figure of *Ammonites kridion* (renamed *A. hartmanni* by Oppel), like the Dorset form here described, shows not a bipartite, but a tripartite, external saddle, and that the species has so frequently been misidentified, the name is perhaps not a good one. On the other hand, none of

[1] 'Yorkshire Type-Ammonites' vol. i (1911) p. *vi*.

[2] 'Cefalopodi Liassici del Monte di Cetona' pt. ii, Palæontographia Italica, vol. viii (1902) p. 190.

[3] 'Paléontologie Française: Terrains Jurassiques' 1844, pl. li, figs. 1–2, & 4–6, *non* fig. 3.

the forms of this group of *Arnioceras* can be identified with other known species. One new form somewhat resembles Reynès's *A. geometricus* Phillips, var. *hartmanni* Oppel ('Monographie des Ammonites' pl. xv, fig. 19)[1] but has flattened lateral areas, a rectangular whorl-section and closer costation. *Arnioceras hartmanni* var. *plicata* Fucini[2] has its closer costation, but different periphery and suture-line. This new form is transitional to another resembling *Ammonites patti* Dumortier,[3] with still flatter periphery; on the other hand, *Arnioceras hartmanni*, with angular periphery, leads to smooth forms, comparable to *A. nigrum* (Blake), and having body-chambers at small diameters. This group of forms is thus fairly homogeneous, and the suture-lines, all of the type of that of *A. semicostatum* (Young & Bird), have short and comparatively wide lobes and saddles, like A. d'Orbigny's and Reynès's (exceptional) figures. It is to be noted, however, that in, for instance, an example of *A. semicostatum* from Yorkshire, the two types of *Arnioceras* suture-lines (namely, one having a deep and narrow first lateral lobe ending in two long prongs, and the other a shallow wide principal lobe) occur, not only on consecutive septa, but on opposite sides of the same septum, and therefore care has to be exercised in the examination of suture-lines.

The examples of *Arnioceras* from the beds below the *brooki*-horizon down to bed 72 are hardly identifiable specifically; but in beds 72 & 71 forms of *Arnioceras* possessing smooth inner whorls are dominant. They are, with some hesitation, compared to '*A. semicostatum*', and certain examples resemble the form with oblique costæ that Quenstedt,[4] in his latest work, erroneously identified with his species *Ammonites ceratitoides* of 1849.[5] Of Quenstedt's later *Arnioceras*, only the Oil-Shale form *A. falcaries olifex* ('Ammoniten des Schwäbischen Jura' 1883, pl. xviii, fig. 10) can have any affinity with the types here described; but this species is incompletely known. Numerous small forms remain smooth to the diameter of *Arnioceras flavum* S. Buckman,[6] which species was described as having the periphery of Quenstedt's *Ammonites miserabilis*. But this, apparently, is an error; for Quenstedt did not describe his *A. miserabilis* as 'having a keel like a piece of string rolled round,' although on p. 71 of his 'Jura' (not his 'Ammoniten des Schwäbischen Jura') he says that it looks like coiled string, obviously in respect of its very evolute character.

[1] In the text (p. 4) Reynès considered *A. hartmanni* Oppel to represent the young stage of '*A. geometricus* Phillips,' and put it in the 'zône à *Ammonites multicostatus*.'

[2] Pal. Ital. vol. viii (1902) p. 198 [158] & pl. xxvi [xxix], fig. 12.

[3] 'Études Paléontologiques sur les Dépôts Jurassiques du Bassin du Rhône' vol. ii (1867) p. 119 & pl. xxi, figs. 16–17.

[4] 'Ammoniten des Schwäbischen Jura' 1883, pl. xiii, fig. 8.

[5] 'Petrefactenkunde Deutschlands, pt. i: Die Cephalopoden' p. 239 & pl. xix, fig. 13.

[6] 'Jurassic Chronology: I—Lias' Q. J. G. S. vol. lxxiii (1917–18) p. 298 & pl. xxxi, fig. 2.

Moreover, *A. miserabilis* is an early form typically occurring in the 'Schneller' Limestones of Quenstedt's Lias α (subzone of *Arietites multicostatus* in E. Haug[1]—Neues Jahrb. vol. ii, 1887, p. 101), and below the Pentacrinite-Bed, which is probably the *alcinoe* horizon of this paper. In Yorkshire, *Ammonites miserabilis* occurs in the same blocks with *Arnioceras acuticarinatum* (Simpson), and the latter is a characteristic fossil of the *scipionianum* beds near Broadford in Skye. On the other hand, *A. flavum, A. nigrum, A. semicostatum, A. anageneticum* S. Buckman, *A. douvillei?* (Bayle), *A. difforme* (Blake *non* Emmrich), and other comparable species of this '*Eparnioceras*' type may be later even than the *hartmanni* subzone: for, to judge by specimens in the British Museum (C 2912 & 62370), they are associated with an early form of *Xipheroceras* [cf. *X. capricornoides* Quenstedt[2]] suggestive of the *birchi* zone. Unfortunately, the Dorset examples of this group, occurring in what appears to be a nodular limestone, with the shells well preserved in yellowish or greenish calcite, have not yet been found *in situ*. It is, therefore, considered inadvisable to identify any of the crushed smooth forms of beds 71 & 72 with the true *Arnioceras semicostatum* and *A. flavum* occurring in limestone.

Little need be said about the *Arnioceras* of the *alcinoe* horizon and the underlying *Agassiceras* beds. No satisfactory specimen of the Gloucestershire *Arnioceras bodleyi* (J. Buckman) was found, and, from a comparison of Dumortier's[3] pl. xxx, figs. 1 & 2 (*A. geometricus* from the '*oxynotum*' zone) with pl. vii, fig. 6 (*A. geometricus* from the *bucklandi* zone), it will be seen that similar types of *Arnioceras*, in the Rhône Basin also, are widely separated stratigraphically. Nearly all the specimens are badly crushed; moreover, *Arnioceras anomaliferum* Fucini, to which some of the specimens are compared, itself includes a doubtful series of forms, and *A.* cf. *speciosum* Fucini, also provisionally included in the list, may or may not be identical with Buckman's *A. fortunatum*, which Fucini considers to be a synonym of his Italian species.[4]

In the lowest bed, Table Ledge (53), a rather distinctive new but generally crushed form, is fairly common. It resembles the species wrongly included by Quenstedt ('Ammoniten des Schwäbischen Jura' pl. xl, fig. 5) in Hehl's *Ammonites kridion*; but the ribs are even less distinct, especially on the outer portion of the sides. Hyatt[5] included Quenstedt's figure in his *Arnioceras kridioides*, but wrongly, as F. Wähner[6] pointed out.

[1] Haug fixed the type, but confused with it *A. nigrum* Blake.

[2] 'Ammoniten des Schwäbischen Jura' 1883, pl. xvii, fig. 11.

[3] 'Études Paléontologiques . . . Bassin du Rhône' vol. ii, 1867.

[4] 'Appunti di Ammonitologia' Boll. Acc. Gioenia di Sci. Nat. Catania, Fasc. 47 (1919) 1920, p. 8.

[5] 'Genesis of the Arietidæ' 1889, p. 171.

[6] 'Beiträge zur Kenntnis der Tieferen Zonen des Unteren Lias in den Nordöstlichen Alpen' pt. vii, Beitr. Pal. Œst.-Ung. vol. ix (1894) p. 5, footnote 3.

(C) Genus *Agassiceras* Hyatt.

This is here taken to include the *striaries-sauzianus* group, as emended by S. Buckman, 1909 (non *Agassiceras*, Hyatt emend. Haug 1887). It is represented by a number of forms that range from below Table Ledge (53): that is, from below the limits of the present section, to the *alcinoe* bed (70). *Agassiceras striaries* (Quenstedt), *A. sauzeanum* (A. d'Orbigny), *A. spinaries* (Quenstedt), distinguished from the nearly allied French species by closer costation, are the commonest forms, the smooth *A. striaries* apparently characterizing the lower half of these beds. A new species, *A.* REYNESI, nom. nov. (=*Ammonites multicostatus* Sowerby, var. *spinaries* Quenstedt in Reynès, 'Monographie des Ammonites' 1879, pl. xxiv, figs. 25–28, Coll. W. D. L. 4236), forms a morphological transition to some species of the genus *Pararnioceras*, dealt with below, and Herbich's *Arietites stellaris* =*A. obtusus* var. *vulgaris* Vadasz [1] seems also to belong to this group. *Agassiceras* cf. *terquemi* (Reynès),[2] recorded from bed 70 c, is a doubtful example; accordingly, no *Agassiceras* of the typical *sauzeanum* type has been found in bed 70 c.

With regard to the interpretation of the genus *Agassiceras*, it may here be remarked that forms comparable to *Ammonites personatus* and *A. resupinatus* Simpson, probably also *A. subtaurus* Reynès and *Ætomoceras* DECIPIENS nov. (=*A. multicostatus* Simpson *non* Sowerby, B.M. C 22067 a, b='*Agassiceras* sp.,' pl. clxxxvii, fig. 3 in Buckman, *op. cit.* vol. iii, 1920) occur in the *scipionianum* beds of Skye and Yorkshire, and are here excluded from *Agassiceras*; but the ancestral forms of both *Ætomoceras* and *Agassiceras* have to be looked for in the stock that produced the still earlier 'Coronicerates' discussed in my paper on the Lower Lias of Skye. The tendency of *Agassiceras*, however, is to 'delay' the development of bisulcation, common to all these derivatives of the genus *Ammonites* sensu stricto (*Ammonites* Bruguière, restricted to the group of *A. bisulcatus* (Bruguière) A. d'Orbigny, pl. xliii [3]). A similar tendency in early '*Eparnioceras*' leads to *Cymbites*, which genus, therefore, cannot be united with *Agassiceras*, as was done by Haug [4] and Pompeckj.[5] Like *Psilophyllites* Spath,[6] *Cymbites* is a good illustration of simplification. The resemblance of species of *Agassiceras* of the type of *A. davidsoni* (Dumortier *non* A. d'Orbigny) or of *A. berardi* (Dumortier) [7] with the scaphitoid *Cymbites* is, moreover, not very close.

[1] 'Unterliasische Fauna von Alsórákos, &c.' Mitt. Jahrb. K. Ung. Geol. Anst. vol. xvi (1908) p. 377 (71) & pl x, fig. 3 only.

[2] 'Monographie des Ammonites' 1879, p. 4 & pl. xix, figs. 9–12.

[3] L. F. Spath, Geol. Mag. 1922, p. 173.

[4] Neues Jahrb. vol. ii (1887) p. 93.

[5] 'Ueber Ammonoiden mit "anormaler Wohnkammer"' Jahresh. Ver. Vaterl. Naturk. Württ. vol. l (1894) p. 238.

[6] 'Development of *Tragophylloceras loscombi*' Q. J. G. S. vol. lxx (1914) p. 351.

[7] 'Études Paléontologiques sur les Dépôts Jurassiques du Bassin du Rhône' vol. ii (1867) pl. xxi, figs. 5–7.

(D) Genus *Pararnioceras* Spath.

This genus was created[1] for *A. alcinoe* Reynès (pl. xxiii, figs. 7–11), the type being specimen 2713 (Coll. W. D. Lang), which is identified with Reynès's species. This occurs rather abundantly in bed 70c, hence called the '*alcinoe* bed,' and is there associated with a more closely costate species, which, however, is laterally not so flat as *P. planaries* (Reynès). Another new species from the same bed is comparable to *P. nodosaries* (Quenstedt), and differs from '*Arietites multicostatus*' Wright (*non* Sowerby), pl. iv, in being still more densely costate. A new and equally large species, occurring with the above in bed 70 c, has a subtrigonal whorl-section, and differs from *Paracoroniceras gmuendense* (Oppel) Reynès sp. (pl. xvi, figs. 1–2) chiefly in its obscure ornamentation and in the great width of its first lateral saddle.

Some smaller crushed examples from bed 70c may represent the young of *Pararnioceras*. One of these (No. 4649) somewhat resembles *Ammonites breoni* Reynès (*op. cit.* 1879, p. 5 & pl. xxxii, figs. 16–17), and suggests connexion with the younger genus *Arietites*. These smaller specimens are, unfortunately, in a bad state of preservation.

Forms of the group of *Epammonites latesulcatus* (Quenstedt) Schmidt sp., notably *E. parthenope* and *E. isis* (Reynès), *E. paolinæ* (Reynès), and *E. compressaries* (Reynès, *non* Quenstedt), which by way of *E. aglaë* (Reynès) are connected with the true *Arnioceras*, greatly resemble some species of *Pararnioceras*; but they do not seem to range beyond the *gmuendense* and *scipionianum* zones, to judge from the collections which I made in Skye. In Warwickshire also, at Stockton, with '*Schlotheimia*' *charmassei* (A. d'Orbigny), in the '*bucklandi* beds,' occur *Epammonites aglaë*, *E.* sp. nov. (cf. *conybeari* Reynès *non* Sowerby, pl. xii), *E.* cf. *breoni?* and *E.* cf. *hebe* (Reynès), the inner whorls of all of which suggest an *Arnioceras*-origin. The early *Epammonites*, then, closely connected with the true *Arnioceras* of the *Coroniceras* Beds, may be considered distinct from the more or less homœomorphous *Pararnioceras*, a specialized megalomorph offshoot of another Arietid stock. Nothing like the forms of *Pararnioceras* here described has been discovered in the beds below 70c of the Charmouth section, and in Gloucestershire and Worcestershire, where *Agassiceras sauzeanum* occurs plentifully, *Pararnioceras* also seems to be absent. Thus stratigraphical occurrence and faunal association suggest an *Agassiceras* origin for *Pararnioceras*; and from *A. reynesi*, sp. nov. to *Pararnioceras alcinoe* (Reynès) or *P. nodosaries* (Quenstedt) there is only a step. Until, however, the inner whorls of *Pararnioceras* are known, accurate comparison with both *Epammonites* and *Agassiceras* is impossible.

[1] Abs. Proc. Geol. Soc. No. 1079, January 13th, 1922, p. 30.

(E) Genus *Arietites* Waagen.

This genus, restricted to the *turneri* group (not including such forms as, for instance, *Ammonites denotatus, tenellus* Simpson, *A. impendens* Young & Bird, which are more nearly allied to *Asteroceras*), first appears on the Dorset coast at about 36 feet below the *birchi*-nodular bed. Its upward range is not yet determined; but, if we may judge by examples of *Arietites* collected at distances of 5 to 10 feet above the *birchi*-tabular and still close to the true *Arietites turneri*, the genus passes beyond the limits of the section here described. The specimen from bed 77, closely allied to *A. turneri* as stated, is the '*Arietites* sp.,' included by Mr. S. S. Buckman [1] in the '*brooki* series.' Dr. Lang's specimen from near bed 80 [2] is too badly preserved for certain reference to either *Asteroceras* or *Arietites*.

The earliest forms of *Arietites*, from bed 73, seem to be referable to three new species. One with rather distant costation looks somewhat like *Ammonites bucklandi costaries* Quenstedt [3]; another is homœomorphous with the later true *Arietites turneri*; and the third has closer costation than the others. The poor preservation of the inner whorls in all three and the absence of suture-lines make it necessary for the present to refer them to new species, on the evidence of external characters and in view of the fact that even in the later *Arietites* of the *brooki* bed the inner whorls are very distinct from those of the still later *turneri* group. It should be pointed out, however, that the inner whorls of the three new species are not markedly smooth; whereas one specimen at least of the presumably late *Arietites plotti* (Reynès) has the 'delayed' inner whorls of *A. brooki*. Similarly, in *brooki*-like *Asteroceras* of a much later date (but until now generally confused with the earlier *Arietites*) the inner whorls may resemble those of the true *A. brooki*.

The real horizon of the last-named species was long a matter of speculation among workers on ammonites, and it can only now be definitely stated, thanks to Dr. W. D. Lang's careful collecting, that this horizon is some 23 feet below the *birchi* bed and not above it, as had been argued from biological considerations: that is, it is not post-*turneri* in date, as it was thought to be in development. The *brooki* bed is crowded with small *Arietites*, differing in thickness and in the spacing of the ribs; but this great variability is apparently confined to young individuals, and the adult specimens all conform to the typical *A. brooki*. It may be added that Quenstedt's fig. 7 of pl. xvii (*A. scipionianus olifex*) may be a true *Arietites* of this group, whereas his '*Ammonites brooki* β' (pl. xx, figs. 11 & 12) is an *Asteroceras*.

It has already been mentioned that no species of *Arnioceras*

[1] Q. J. G. S. vol. lxxiii (1917–18) p. 298.
[2] Proc. Geol. Assoc. vol. xxv (1914) p. 316.
[3] 'Ammoniten des Schwäbischen Jura' 1883, pl. xi, fig. 1.

occurs in the *brooki* bed, and, conversely, no *Arietites* in the Black *Arnioceras* Limestone (=*hartmanni* bed); indeterminable species of *Arietites* were, however, found 3 feet below and 1 foot above the latter bed.

From horizon 74r, 9 feet below the *birchi*-nodular, was obtained a new species of *Arietites*, immature, but with an *Asteroceras*-periphery, similar to that of Quenstedt's *Ammonites brooki* β, just mentioned.

There is a specimen in the Tomes Collection in the Natural History Museum (C 16501) from Weston Hill (Gloucestershire), marked as occurring 'with *Ammonites brooki*,' that probably belongs to the same or an allied, inflated, yet evolute species of *Arietites*; it cannot well be compared, however, on account of difference in size. This example is associated in the same collection with numerous *Arietites* of the group of *A. turneri*, *A. turgescens*, and *A. plotti*, all from Worcestershire and Gloucestershire; but there is no true *A. brooki*. Moreover, those examples that have the inner whorls preserved (C 6154 from Eckington, near Pershore, and C 16506 & C 16884 from Nobb's Farm, Weston) belong to the 'accelerated' *turneri*, and not to the early and rather distinct *brooki* group. A number of *Arietites* of the *turneri* group, kindly sent by Mr. J. W. Tutcher, include examples comparable to the specimen figured by Mr. S. S. Buckman in 'Type-Ammonites' vol. iii (1921) pl. ccxxi. A–B, and *A. turgescens*, from the neighbourhood of Bristol, where the true *A. brooki* again seems to be missing. A specimen of *A. turneri* from Ashley Down, and a more distantly costate *Arietites* from Salford, near Bristol, are associated with *Microderoceras*. Mr. Tutcher believes that these *Arietites* come from below the *birchi* bed, and, according to his statement in 1918 (in S. S. Buckman, Q. J. G. S. vol. lxxiii, p. 280), numerous specimens of *Arnioceras* are associated with *Arietites turneri* in his district. I am thus not at present in a position to decide whether Mr. Tutcher's *turneri* zone corresponds, as seems likely, with the *birchi* zone of this paper (or at least with post-*brooki* beds in the Dorset sequence) or whether there is a condensation of the whole six post-*sauzeanum* beds into his one '*turneri* zone,' as might also be surmised from Mr. Tomes's record (in coll.) of *Arietites* with *Agassiceras*.

Two very immature *Arietites* from the same bed as the new species just mentioned present no indications yet of the keel at diameters of 6 to 7 mm.

An abundant development of *Arietites*, notably *A. turneri*, occurs in the *birchi*-tabular; and Quenstedt's *Ammonites serpentinus olifex* (pl. xviii, fig. 10), from the Oil-Shale with *M. birchi*, probably also represents the true *Arietites turneri* of this horizon. As type of *A. turneri*, J. de C. Sowerby's upper figure was selected by Oppel; the lower figure of pl. cccclii (Min. Conch. vol. v, 1825) is an *Arnioceras* from Watchet, comparable to some of the forms here referred to *A. obliquecostatum* (Zieten) Fucini.

The last-named author's *Arietites* [*'Asteroceras'*] *brooki* and *A. turneri*,[1] by the way, probably are also misidentified.

A. plotti (Reynès) has not been found by Dr. Lang, but I have seen examples in the collections of Dr. Wyatt Wingrave, Mr. James Francis, and Mr. F. H. Butler, with fragments or impressions of large *M. birchi* attached; we may, therefore, take it as fairly certain that the *birchi*-nodular is the home of this common species. *A. PSEUDOBONNARDI*, sp. nov. (=*Ammonites bonnardii* Wright[2] *non* A. d'Orbigny, Natural History Museum, C 1891), which differs from Reynès's *Ammonites plotti* in having coarser ornamentation, and an allied *Arietites*, sp. nov., with feeble ornament and almost smooth outer whorl (No. 2955, Coll. L. F. Spath) probably also came from the *birchi* zone.

(F) Genus *Cymbites* Neumayr.

The genus *Cymbites*, numerously represented in the upper beds of the Shales-with-'Beef,' is a stock the systematic position of which requires consideration as a preliminary to the review of its various representative species.

The type of *Cymbites* is *C. globosus* Neumayr, and the holotype of the species is *Ammonites globosus* Schübler in Zieten ('Die Versteinerungen Württembergs' 1832, p. 37 & pl. xxviii, fig. 2), a doubtful form from the 'Lower Oolites.' Quenstedt in his 'Jura,' as in his 'Ammoniten des Schwäbischen Jura,'[3] and also Oppel[4] considered the form of the Middle Lias δ to represent the 'normal type'; hence *Ammonites centriglobus* Oppel=*Amm. globosus* Quenstedt ['Cephalopoden' 1849, p. 188 & pl. xv, figs. 8 *a*–8 *c*, and 'Ammoniten des Schwäbischen Jura' 1885, pl. lxii, figs. 29 & 30, according to Pompeckj[5]] might be chosen as the genotype. Most writers, however, including Hyatt, Haug, Pompeckj, and Buckman, have connected *Cymbites* with *Agassiceras*, which develops unconstricted but otherwise similar forms. *Cymbites* was thus clearly used for the dwarf-forms of the *lævigatus* group, and the restriction of '*Cymbites*' to the Domerian *Ammonites centriglobus* seems inadvisable. Since this dwarf-development of the Middle Lias cannot satisfactorily be assigned to any known contemporaneous genus, a new name (*METACYMBITES*) may be proposed for it. The suture-line, with deep trifid lobes, is quite different from that of the earlier *Cymbites*. It may be related to Fucini's Cœloceratid genus *Diaphorites*; but Rosenberg's '*Agassiceras*' *arthaberi*[6] probably does not belong to it. Haug's

[1] 'Cefalopodi Liassici del Monte di Cetona' pt. iii, Pal. Ital. vol. ix (1903) pl. xix (xxx) figs. 1–4.

[2] 'Monograph of the British Lias Ammonites' Pal. Soc. pt. ii, 1879, pl. xi, figs. 1–3 & pt. iv, 1881, p. 287.

[3] 'Jura' 1858, p. 172; 'Ammoniten des Schwäbischen Jura' 1885, p. 336.

[4] 'Der Mittlere Lias Schwabens' Jahresh. Ver. Vaterl. Naturk. Württ. vol. x (1853) p. 95 & pl. iii, fig. 7.

[5] Jahresh. Ver. Vaterl. Naturk. Württ. vol. l (1894) p. 239.

[6] 'Die Liasische Cephalopodenfauna der Kratzalpe im Hagengebirge' Beitr. Pal. Œst.-Ung. vol. xxii (1909) p. 271 & pl. xiii, figs. 15–18, pl. xiv, figs. 1–2.

statement[1] that the genetic connexion of the Middle Lias '*Cymbites*' *globosus* with the group of '*Agassiceras*' *lævigatum* seems evident cannot now be accepted, and Pompeckj's proposal to include in a polyphyletic genus '*Cymbites*' all the forms from Dumortier's *Ammonites lævigatus* (*non* Sowerby) of the *angulata* zone, up to the externally similar species of the Middle Lias, is equally objectionable.

It even seems probable that the presumed earliest '*Cymbites*,' namely, the form figured by Dumortier,[2] like *Ammonites semicostulatus* (Reynès) Wähner,[3] is only a homœomorphous development of a Caloceratid stock, wherefore a different generic name (*Protocymbites*) becomes necessary, the genotype to be Wähner's Alpine form (*P. wæhneri*, nom. nov.) with ornamentation different from that of *Cymbites*. I may here add that I would include in the family to which *Protocymbites* belongs, namely Caloceratidæ (*ex* Psiloceratidæ), also the new genera *Paracaloceras* nov. [genotype: *Arietites coregonensis* (Sowerby) Wähner[4] of horizon *a* 3] and *Pseudætomoceras* nov. [genotype: *Arietites abnormilobatus* Wähner[5]] as well as the genus *Tmægoceras* of horizon *a* 2–3, all of which resemble later true Arietids. This genus *Tmægoceras* of course has nothing to do with the Hildoceratid genus *Leukadiella*, nor have the other Hildoceratid genera *Frechiella*, *Achilleia*, and *Paroniceras* any connexion with *Arietites* or *Agassiceras*, as Carl Renz[6] thinks.

Cymbites, then, is a simplified development of an Arietid stock ('*Eparnioceras*'), and characterizes the lower part of Oppel's original *obtusus* zone. Buckman's family Cymbitidæ,[7] which, besides *Cymbites* (by him considered to be an 'anamorph,' not a 'catamorph') includes two Hildoceratids (*Frechiella* and *Paroniceras*), and one Grammoceratid (*Hudlestonia*) must be rejected.

Cymbites lævigatus (Sowerby) occurs in the *brooki* bed (74d) below, in the *birchi*-tabular (76) above, and at one intermediate horizon (74r), 9 feet below the *birchi*-nodular bed. In the Black *Arnioceras* Limestone=*hartmanni* bed (74f) 3 feet above the *brooki* bed, among countless young and smooth *Arnioceras* of the *hartmanni* group, at that stage close to *Arnioceras nigrum* (Blake), and innumerable small *Straparollus* that, at first sight, might be mistaken for immature ammonites, only one minute globose form of *Cymbites (?)* was discovered.

In the *brooki* bed, *Cymbites lævigatus* is associated with a similar globose form (which is neither *globosus* α nor *globosus* β

[1] E. Haug, Neues Jahrb. vol. ii (1887) p. 99.

[2] 'Etudes Paléontologiques sur les Dépôts Jurassiques du Bassin du Rhône' vol. i (1864) p. 116 & pl. xviii, figs. 5–6.

[3] Beitr. Pal. Œst.-Ung. vol. iv (1886) pl. xxvii, fig. 12 only.

[4] *Ibid.* vol. vi (1888) pl. xxii (xli), fig. 1.

[5] *Ibid.* vol. v (1886) pl. xxiii (xxxviii), fig. 5 only.

[6] 'Neue Arten aus dem Hellenischen Jura, &c.' in 'Neuere Fortschritte in der Geologie & Paläontologie Griechenlands' B, Zeitschr. Deutsch. Geol. Gesellsch. vol. lxiv (1912) p. 600.

[7] 'Yorkshire Type-Ammonites' vol. ii (1919) p. *xv*.

of Quenstedt, but is immature) and with a compressed variety of the same species. The numerous young *Arietites* that occur with these forms develop carina and costæ at a very early stage.

In the lenticles 9 feet below the *birchi*-nodular, and in the *birchi*-tabular, the *Cymbites* are associated with young *Microderoceras* that remain smooth or striate to a considerable diameter, and can be distinguished from *Cymbites* chiefly by the complex suture-line, the regular coiling, and the striation when the test is preserved. On the other hand, the *birchi*-tabular contains a form comparable to *Cymbites* (?) *semicostulatus* Reynès (*non* Wähner) sp.,[1] distinguished from the young of *Xipheroceras* by its greater thickness and comparative smoothness. It may be noted that a small malformed example of a *M. birchi* from the *birchi*-nodular has acquired, after an injury, the outer whorl of a *Cymbites lævigatus*, though the mouth-border has a raised lip all round, not a prominent ventral lappet.

From the evidence of Dr. Lang's collection, *Cymbites lævigatus* would appear to be confined to the beds 74d–76; but there is a loose block in my collection that contains the typically excentrumbilicate *Cymbites lævigatus*, in association with *Xipheroceras* of a late type; the block probably came from a bed not yet located higher than the *birchi*-tabular. The *Cymbites* (?) found 'in place' above the *birchi*-tabular are small globose forms, that occur also with the Marston Magna *Xipheroceras planicosta* (typus); in the *Asteroceras-smithi* Bed at Lyme, of the same age as the Marston Marble; and in the (87) Brachiopod Limestone (No. 1093, Coll. W. D. Lang), but these may be young *Asteroceras*. At least, the examples that I have dissected are comparable to the young of *Asteroceras obtusum*; whereas the development of *Cymbites lævigatus* resembles that of (for instance) *Arnioceras nigrum*. None of these later forms has a constricted mouth-border or scaphitoid body-chamber, and it may be noted that the forms from Lias β and δ, included in *Cymbites* by Pompeckj, namely Quenstedt's[2] fig. 46 of pl. xxii, and fig. 38 of pl. xlii, also probably have nothing to do with the *lævigatus* group to which *Cymbites* is here restricted. Mr. Linsdall Richardson's[3] '*Cymbites globosus*' and '*C.* cf. *personatus* (Simpson)' are equally doubtful.

(G) Genus *Sulciferites* Spath.

The family Schlotheimidæ, derived from Psiloceratidæ by way of *Wæhneroceras*, is represented in the material here described by species of *Sulciferites*, to which genus were referred[4] members of the group of *Schlotheimia sulcifera* S. Buckman = *A. sulcatus* J. Buckman, *non* Simpson, the genotype being that species to

[1] 'Monographie des Ammonites' 1879, pl. xxxi, figs. 27–29.
[2] 'Ammoniten des Schwäbischen Jura' 1883–85.
[3] In S. S. Buckman, 'Jurassic Chronology I.: Lias.—Suppl. I' Q. J. G. S. vol. lxxvi (1920) p. 81.
[4] Abs. Proc. Geol. Soc. No. 1079, January 13th, 1922, p. 30.

which an example in the Natural History Museum (C 16416) from Welford Hill (Gloucestershire) belongs. The true *Schlotheimia* attains its maximum development in lower *bucklandi* times, with *S. greenoughi* (Sowerby) and allied gigantic forms. The much later *Sulciferites*, representing Mr. Buckman's 'second wave of *Schlotheimia*,' developing such highly specialized types as *S. boucaultianus* (A. d'Orbigny) and therefore not a 'catamorph,' represents an independent development, probably of the same stock. It is possible that '*Angulaticeras*' of the *oxynotus* zone, Mr. Buckman's 'third wave of *Schlotheimia*' is referable to yet another branch, although its connexion with the family Schlotheimidæ is uncertain. '*Schlotheimia*' *sulcata* (Simpson *non* J. Buckman) belongs to this last group; but *S. dumortieri* Fucini (=*S. deleta* Canavari?), included here by Mr. S. S. Buckman, is considered to be a *Sulciferites* of an earlier horizon.

Sulciferites probably represents a development of *Schlotheimia ventricosa* (Sowerby) and *S. posttaurina* (Wähner), which are of *rotiforme* age.[1] In areas where the intervening *scipionianus* and *sauzeanus* zones are developed, as, for instance, in Skye, Yorkshire, Saltrio, or Alsórákos, no *Schlotheimia* are found that might form a satisfactory connecting-link, although in Warwickshire, as already stated, *Schlotheimia* of the *charmassei* group are associated with *Epammonites* of the *bucklandi* beds. Hyatt considered '*Ammonites charmassei* Hauer' and '*Ægoceras*' *tenuicostatum* Herbich (the latter united with *Schlotheimia marmorea* by Vadasz), to connect the Schlotheimids of the lower *bucklandi* zone with the later *S. angustisulcata* and '*S. lacunata*' of Geyer; and Wright assumed *S. boucaultianus*, known only in one British (Lincolnshire) example, to be a direct descendant of *Schlotheimia charmassei* of the lower *bucklandi* zone. In reality, there is a very considerable gap between the *Schlotheimia* of the *bucklandi* zone, especially the extra-Mediterranean forms, as, for example, *S. angulatoides* (Quenstedt) from Wurtemberg, the horizon of which is known, and the genus *Sulciferites* of the lower *obtusum* zone. '*Schlotheimia*' *d'orbignyana* Hyatt in Schmidt,[2] from the Harzburg Ironstone, somewhat bridges this gap, though its exact horizon is unknown; and derived fragments of *S. angulata* still occur in bed I of the Harzburg Ironstone with *Agassiceras sauzeanum*; *S. charmassei* also has an intermediate position. All the forms figured by Fucini from the Lower Lias of the Monte di Cetona may be *Sulciferites*. On the other hand, *Schlotheimia angustisulcata* Geyer,[3] a Hierlatz form, is not included in *Sulciferites*, its suture-line being of quite a different type and not simple like that of the genotype of *Sulciferites*. Now, Geyer

[1] F. Wähner, Beitr. Pal. Œst. Ung. vol. iv (1886) p. 200.

[2] Palæontographica, vol. lxi (1914) p. 37 & pl. vii, figs. 2–5.

[3] 'Ueber die Liasischen Cephalopoden des Hierlatz bei Hallstatt' Abhandl. K. K. Geol. Reichsanst. vol. xii (1886) p. 258 & pl. iii, figs. 24–25.

stated that his *S. angustisulcata* occurred in the same block with *Arietites semilævis* (Hauer), which (according to Oppel) is an Arietid of the *tuberculatus* zone, and, indeed, is grouped with species of *Arnioceras* by Geyer. *Oxynoticeras oxynotus*, however, also occurs in the same block with *Arietites semilævis*, and both are associated (as, for instance, at Station IV, position No. 5) with *Deroceras bispinatum* (Geyer) and *Schlotheimia geyeri* Hyatt (=*S. lacunata* Geyer *non* J. Buckman), also of the *oxynotus* zone. The *Schlotheimia* of the mixed Hierlatz deposit, then, cannot be accurately dated. Similarly in the Ligurian Apennines (Spezia), where numerous species of *Schlotheimia* occur in the lower beds with limonitic ammonites (*megastoma* to *rotiforme* zones), only *S. boucaultiana* and '*Schlotheimia* sp. indet., cf. *geyeri* Hyatt' have been found in the upper shales with abundant *Arnioceras*.[1] When refiguring '*A. sulcatus*' in the Palæontologia Universalis, Mr. S. S. Buckman pointed out that '*sulcatus*'-like forms had been mistaken for true *Schlotheimia* of the *angulata*-group, and he suggested that

> 'the record for *sulcatus* and allies should be Lower Lias, Sinemurian, zone of *Arnioceras semicostatum*, neighbourhood of Cheltenham, in same bed with *A. bodleyi*.' (1904, p. 39*a* & pl. xxxix.)

Various Gloucestershire species of *Sulciferites* in the Tomes Collection (Natural History Museum) are marked 'with *A. birchi*' (including the specimen on which the genus is based) or 'with *A. brooki*'; but, as already mentioned, these Gloucestershire '*brooki*' fragments do not agree with the true Charmouth *brooki*.

Arnioceras comparable to J. Buckman's *A. bodleyi* occur at Charmouth in the *alcinoe* bed (70c), and *Arnioceras* cf. *nodulosum* (J. Buckman), the horizon of which was considered by Mr. S. S, Buckman[2] to be 'presumably the same as that of *A. bodleyi*, namely the *semicostatum*-zone,' occurs in beds 70 h and 72 e & f, wherefore the *Sulciferites* here referred to '*Ammonites sulcatus*' [*S. sulcifer*], despite their crushed condition, may be assigned to the Gloucestershire species.

The genus *Sulciferites*, at Charmouth, seems to be restricted to a portion of bed 73 (that is, the 6 feet of shales below 'Little Ledge'). *S. sulcifer* is the latest species, ranging from bed 73 m to 73 p; *S.* cf. *angustisulcatus* (Geyer) Tillmann sp.[3] is the earliest, namely in beds 73 f to 73 h. *S.* cf. *dumortieri* (Fucini)[4] (=*A. lacunatus* Dumortier[5] *non* J. Buckman) occupies an intermediate position (73 j–73 m), as it is also intermediate between

[1] A. Fucini, 'Sopra gli Scisti Lionati del Lias Inferiore dei Dintorni di Spezia' Atti Soc. Tosc. Sci. Nat. Pisa, Mem. vol. xxii (1906) p. 130.

[2] Palæontologia Universalis, 1905, p. 77*a* & pl. lxxvii.

[3] 'Die Fauna des Unteren & Mittleren Lias in Nord & Mittel-Peru' Neues Jahrb. Beilage-Band xli (1917) p. 670 & pl. xxi, fig. 2.

[4] 'Cefalopodi Liassici del Monte di Cetona' pt. iii, Pal. Ital. vol. ix (1903) pl. xxiv (xxxv), fig. 9.

[5] 'Études Paléontologiques sur les Dépôts Jurassiques du Bassin du Rhône' vol. ii (1867) p. 120 & pl. xxi, figs. 18–20.

the other two forms in the character of its costation. Canavari[1] included Dumortier's form in his '*Ægoceras*' *deletum*; but, since it is doubtful whether the Spezia ammonite is the same species as the French, Fucini's name is here adopted. Pompeckj[2] wrongly included Dumortier's much earlier form in *Schlotheimia lacunata* (J. Buckman), of the *oxynotus* zone.

(H) Genus *Microderoceras* Hyatt.

The earliest forms of this genus, apparently close to *M. birchi* (Sowerby) but not well enough preserved to be definitely identified therewith, occur at horizon 74 g, 18 feet below the main *birchi* bed. About 18 inches higher, in 74 j, was found a crushed *Microderoceras* (No. 4346) with two closely-approximating rows of tubercles at a comparatively small diameter; whereas, for instance, the form figured by Quenstedt,[3] of which the mode of preservation indicates the *birchi* (nodular) bed as the source, has the outer whorl with two rows of tubercles close together, but the inner whorls almost smooth to an exceptionally large diameter. It is noteworthy, however, that forms apparently indistinguishable from the badly-preserved example of bed 74 j occur in both the *birchi*-nodular and the *birchi*-tabular beds.

Specimens of *Microderoceras* from horizons 74 k, 16 feet below the *birchi* (nodular) bed, and 74 m, 14¾ feet and 14 feet below the *birchi* bed, also a more closely costate variety from 74 o, 10½ feet below the *birchi* bed, are all too young or too badly preserved for exact specific identification. In bed 74 r, 9 feet below the *birchi* bed, the ammonites, including *Arietites* and *Cymbites*, are again preserved in calcite, as in the *birchi* bed, and not as crushed impressions in shales; but the *Microderoceras* are all small. They include one curious form having a single row of median lateral tubercles at the diameter of 15 millimetres.

Crushed impressions of *Microderoceras* occur again at distances of 2 feet, 18 inches, 15 inches, and 14 inches below the *birchi* bed; but the maximum development of the genus is in the main *birchi* (nodular) bed. Whereas all the earlier forms of *Microderoceras*, with the exception of fragments from 18 inches below this bed, are small, the numerous specimens of *M. birchi* in the *birchi*-nodular, including those figured by Sowerby,[4] Wright,[5] and Reynès,[6] attain large dimensions. It has already been mentioned that the only other ammonites in this *birchi*-nodular bed are *Cymbites* and *Arietites* of the *plotti* group, although the latter

[1] 'Beiträge zur Fauna des Unteren Lias von Spezia' Palæontographica, vol. xxix (1882) p. 166 (44).

[2] 'Beiträge zu einer Revision der Ammoniten des Schwäbischen Jura' pt. i, Jahresh. Ver. Vaterl. Naturk. Württ. vol. xlix (1893) p. 237.

[3] 'Ammoniten des Schwäbischen Jura' 1883, pl. xviii, fig. 1.

[4] 'Mineral Conchology' vol. iii (1820) p. 121 & pl. cclxvii.

[5] 'Monogr. Brit. Lias Ammonites' Pal. Soc. 1882, p. 332 & pl. xxiii.

[6] 'Monographie des Ammonites' 1879, pl. xxxviii.

have not been found by Dr. Lang. It is interesting to note that many of the examples of *Microderoceras birchi* are malformed.

In the '*birchi*-tabular' bed, immediately above the *birchi*-nodular, the number of individuals of *M. birchi* is very great; but they are generally of small dimensions, and associated with *Arietites turneri* and *Xipheroceras.*

(I) Genus *Xipheroceras* S. S. Buckman.

This genus is abundantly represented in the '*birchi*-tabular' at the upper limit of the section here described. The commonest form has an oval compressed section, and may be identical with the crushed *Ammonites capricornoides* of Quenstedt,[1] for this also seems to have the ventral differentiation of the costæ far less pronounced than the later *Xipheroceras planicosta* (Sowerby): that is to say, there is neither a distinct latero-peripheral angle, nor appreciable flattening of the costæ on the venter. The inner whorls may remain smooth or slightly striate to a comparatively large diameter, and consequently distinction of very young examples from the equally smooth *Microderoceras birchi*, with which they are associated (but which has a much more complex suture-line), is not always easy. The inner whorls, however, are rather variable, as they are in the later *X. planicosta*, and some examples, transitional to the true *X. planicosta*, occur already in the '*birchi*-tabular.'

Both the genus *Xipheroceras* and the less simplified *Microderoceras*, dealt with above, are included in the family Deroceratidæ. It is probable, as Prof. Haug thinks,[2] that this family is derived from Lytoceratidæ, and has no connexion with, for example, *Paracaloceras centauroides* (Savi & Meneghini), remarkable for its 'retarded' inner whorls, with which, after Canavari,[3] I was at one time inclined to connect *Microderoceras*.[4]

The suture-line development of both *Xipheroceras* and *Microderoceras* was worked out, and the suture-line of *M. birchi*, at 25 mm. diameter, shows great resemblance to that of, for instance, *Ectocentrites herbichi* (Bonarelli) as figured by Vadasz,[5] whereas in, for example, *Deroceras* [*Derolytoceras?*] *pecchiolii* (Meneghini) Fucini[6] the oblique second lateral saddle is indicated, although the high siphonal lobe still retains its Lytoceratid character. At a diameter of 10 mm., the suture-line of *M. birchi* is close to that

[1] 'Ammoniten des Schwäbischen Jura' 1883, pl. xvii, fig. 11.

[2] 'Traité de Géologie' vol. ii, fasc. 2 (1910) p. 950.

[3] *Op. cit.* 1882, p. 190 (68).

[4] 'Notes on Ammonites' Geol. Mag. 1919, p. 175.

[5] 'Unterliasische Fauna von Alsórákos, &c.' Mitt. Jahrb. K. Ung. Geol. Reichsanst. vol. xvi (1908) pl. ix, fig. 4 *a*: '*Ægoceras adnethicum* (Hauer) var. *involuta*, nov.'

[6] 'Cefalopodi Liassici del Monte di Cetona' pt. iii (1903) p. 179, pl. xxiv (xxxv), fig. 12 & pl. xxvii (xxxviii), figs. 3–7, p. 181, text-fig. 102. (The genus *Derolytoceras* Rosenberg ought really to include only the Domerian forms.)

of *X. planicosta*, as figured by F. von Hauer.[1] The latter, however, has a comparatively small first lateral lobe, whereas the most striking feature of the development of the suture-line in *Microderoceras* is the width of the principal lobe. *Xipheroceras*, then, may be a simplified branch of the same stock, rather than connected with *Agassiceras*, as I at one time thought probable.[2]

In North-Western Europe: that is, outside the Mediterranean province, Deroceratids, unfortunately, are exceedingly rare in pre-*birchi* times. Three fragmentary specimens of a form comparable to *Ammonites circumdatus* (Martin) Reynès[3] from Welford Hill (Gloucestershire) in the Tomes Collection (B.M. C 17265–67) are the only British examples that I have seen. The age of this form, however, given as '*bucklandi*' in Reynès, is doubtful.

Ectocentrites adnethicum (Hauer) is of Sinemurian age, and has nothing to do with the genus *Anisoloboceras* Trueman[4] or the family Liparoceratidæ. It may also be added here that *Ectocentrites* still occurs in the *Sulciferites-Arnioceras* shales of Spezia.

(J) Summary of New Names.

METACYMBITES, gen. nov. (p. 76).

Genotype: *Ammonites centriglobus* Oppel.

PROTOCYMBITES, gen. nov. (p. 77).

Genotype: *P.* WÆHNERI, nom. nov. = *Arietites semicostulatus* Wähner *non* Reynès sp.

PARACALOCERAS, gen. nov. (p. 77).

Genotype: *Arietites coregonensis* (Sowerby) Wähner.

PSEUDÆTOMOCERAS, gen. nov. (p. 77).

Genotype: *Arietites abnormilobatus* Wähner.

HYPASTEROCERAS, gen. nov. (p. 84).

Genotype: *Asteroceras? ceratiticum* Fucini.

SLATTERITES, gen. nov. (p. 87).

Genotype: *Ægoceras slatteri* Wright.

Agassiceras REYNESI, nom. nov. (p. 72).

= *Ammonites multicostatus* Sowerby, var. *spinaries* Quenstedt, in Reynès.

Ætomoceras DECIPIENS, nom. nov. (p. 72).

= *Ammonites multicostatus* Sowerby in Simpson = '*Agassiceras* sp.' in Buckman.

Arietites PSEUDOBONNARDI, nom. nov. (p. 76).

= *Arietites bonnardii* (Wright *non* A. d'Orbigny).

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[1] 'Ueber die Cephalopoden aus dem Lias der Nordöstlichen Alpen' Denkschr. K. Akad. Wissensch. Wien, vol. xi (1856) pl. xvi, fig. 6 ('*A. planicostatus*' Sowerby).

[2] Geol. Mag. 1919, p. 175.

[3] 'Monographie des Ammonites' 1879, pl. xxviii, figs. 19–22.

[4] 'Evolution of the Liparoceratidæ' Q. J. G. S. vol. lxxiv (1918–19) p. 263 & p. 286.

(K) General Results.

The distribution of the ammonites in the Shales-with-Beef is summarized in the table facing this page. It will be seen that the family Arietidæ is dominant throughout, as it is for the whole of the Lower Sinemurian. Of the five genera of this family, two range up from beds below the limits of the section here described: namely, *Agassiceras* and *Arnioceras* (*sensu lato*). The true *Arnioceras* (including the well-known *A. geometricum*), in fact, characterizes beds in the *bucklandi* zone very considerably below the *Agassiceras* beds; on the other hand, the very late *A.* ('*Eparnioceras*') *semicostatum*, which in museum specimens occurs associated with *Xipheroceras*, has not yet been found in place, and may prove to belong to beds even higher than the highest *Arnioceras* bed of the table. *Arietites* and *Cymbites* range up into beds above the limits of the section here described, but probably not very high, for *Asteroceras* soon becomes the dominant Arietid genus. The only Arietid genus, then, proper to the Shales-with-Beef is *Pararnioceras*, here considered to be a specialized offshoot of *Agassiceras*. It is also the only genus in these shales that commonly reaches large dimensions, although one fragment of an *Arietites brooki* of gigantic size has been found by Dr. Lang in the *brooki* bed, and large *Microderoceras*, of course, occur again in the *birchi*-nodular, near the top of the section.

The Schlotheimid genus *Sulciferites* and the two Deroceratid genera *Microderoceras* and *Xipheroceras* must be looked upon as cryptogenous genera (in Neumayr's and Haug's sense), which have probably immigrated from the Mediterranean Province. The enormous quantities in which some of these shells, as, for example, *Microderoceras birchi*, are found in certain beds, including all stages of growth, indicate that the organisms lived on the spots where their shells now occur, and that there was no 'transgressive distribution' of drifted shells from other regions, as Prof. J. Walther held.[1]

As regards the two Deroceratids, it has already been mentioned that the Mediterranean genera *Ectocentrites* and *Derolytoceras* (?), with which the family Deroceratidæ is here connected, occur at Spezia and the Monte di Cetona in beds yielding abundant *Arnioceras* and *Sulciferites*. It may be assumed that these beds are homotaxial, if not actually isochronous, with the Dorset strata. Other new types found in Italy, however, as, for instance, *HYPASTEROCERAS*, gen. nov. (genotype: *Asteroceras* (?) *ceratiticum* Fucini, pt. iii, Pal. Ital. 1903, pl. xxiii, figs. 1 *a*–1 *c*) or the forms probably misidentified as '*Vermiceras*,' make it appear probable that the succession between the *Agassiceras-sauzeanum* beds below and the *Xipheroceras-planicosta* beds above is more complete there than it is at Charmouth. For the present, however, it

[1] 'Einleitung in die Geologie, &c.' pt. ii (1893) p. 516.

TABLE SHOWING THE DISTRIBUTION OF THE AMMONITES IN THE 'SHALES-WITH-BEEF.'

Zone	Horizon:		Family ARIETIDÆ: *Arietites.*	*Arnioceras.*	*Cymbites.*	*Agassiceras.*	*Paranioceras.*	Family SCHLOTHEIMIDÆ: *Sulciferites.*	Family DEROCERATIDÆ: *Microderoceras.*	*Xipheroceras.*
Part of *obtusus* zone (Oppel).	*turneri* [*birchi* tabular].	76	*turneri.*		*lævigatus.* cf. *semi-costulatus.*					*capricornoides.*
	birchi.	75, 74 g	*plotti. pseudobonnardi.* sp. nov. sp. juv.		*lævigatus.*				*birchi.*	?
	hartmanni.	74 f, 74 e		*hartmanni.*	cf. *globosus (?).*					
	brooki.	74 c–d	*brooki.*		*lævigatus.*					
	sulcifer.	74 b, 73 a	3 sp. nov.	cf. *semi-costatus.*				*sulcifer. dumortieri.* cf. *angustisulcatus.*		
	Arnioceras sp.	72, 70 f		*nodulosum.*						
tuberculatus zone (Oppel).	*alcinoe.*	70 a–e		*bodleyi.*			*alcinoe group.*			
Part of *bucklandi* zone (Oppel).	*Agassiceras* sp.	69, 62		cf. *insigne.*		*sauzeanum. spinaries. gaudryi.*				
	striaries.	61, 55		*oblique-costatum.*		*sauzeanum. spinaries. striaries.*				
	sp. nov.	54, 53		sp. nov.						
	TABLE LEDGE.									

need only be pointed out that Prof. Haug[1] already recorded this appearance of cryptogenous types at the base of his Lotharingian (namely, his zone of *Microderoceras birchi*, in which he includes *Pararnioceras nodosaries* of the *alcinoe* bed).

Now, the appearance of such new types is often due to changes in the shore-line or transgressions of the sea. Such, however, cannot be proved in the present case, although there may be discontinuities in the succession in Dorset, as, for instance, at the horizon of the *alcinoe* bed, which, with its large ammonites, presents the appearance of a condensed stratum, suggestive of redeposition *in situ*, and is the only bed in which Dr. Lang found a *Gryphæa* ('of the *G. incurva* facies'). Other beds of friable marl occurring sporadically in the succession may also indicate disturbance by current-action or periods of temporary emergence. The neighbouring Mendip axis, of course, was continually oscillating, and the mixture of *Agassiceras* and *Arnioceras* with *Arietites* and *Microderoceras* (known from parts of Gloucestershire where *Pararnioceras* seems to be absent) suggests a composite bed with several non-sequences above the *sauzeanum* subzone, due to this continual movement. That is to say, in Gloucestershire there probably occur only a few remnants of the various horizons here described. In any case, the series of beds under consideration represent a shallow-water formation. During the intervals of submergence, there was in Dorset rapid deposition, indicated by the crushing of the shells; and some layers particularly rich in calcium carbonate may have formed concretions or continuous limestones, after the manner of those that Prof. Walther[2] records as forming between the tide-marks at Suez.

The fact that ammonites are common in these shallow-water formations need not cause surprise. Many ammonites probably lived very much like the recent *Nautilus*, chiefly crawling at the bottom, but able to swim well and quickly,[3] and doubtless most of the ammonite families had their home in the comparatively shallow-water regions of the continental shelves. Lytoceratidæ and Phylloceratidæ were probably pelagic, and preferred warm surface-water or currents[4]; which supposition may explain why they are not confined to the Mediterranean regions, but occasionally became abundant elsewhere, as in the Yorkshire Upper Lias or the Dorset Inferior Oolite, in neither of which areas the water can have been very deep. On the other hand, the bituminous character of some of the shales and their occasional richness in metallic sulphides might suggest that the conditions were like those prevailing in the Black Sea at the present day: namely, a superficial layer of water of low specific gravity, with abundant nectonic and planctonic organisms, and 'regions of death' below, rich in salts, poor in

[1] Traité de Géologie, vol. ii, fasc. 2 (1910) p. 954.
[2] 'Einleitung in die Geologie, &c.' pt. iii (1894) p. 699.
[3] L. F. Spath, 'Notes on Ammonites' Geol. Mag. 1919, p. 32, footnote (3).
[4] *Id.* 'Jurassic Ammonites from East Africa, &c.' Geol. Mag. 1920, p. 362.

oxygen, and poisoned by hydrogen sulphide.[1] In such bituminous shales, only nectonic or pelagic forms of ammonites would be expected to occur. Now, in the Suabian *Posidonomya* Shales, which Pompeckj[2] considered to be such a 'fossil Black Sea,' *Dactylioceras* is throughout[3] by far the commonest ammonite, although the probably pelagic *Phylloceras* and *Lytoceras* and nectonic Harpocerates are also numerous. The occurrence of beds of maximum abundance, including 'nests' of immature ammonites, alternating with layers in which these fossils are rare, then the occurrence of nodules or limestone-bands in places in the succession make it probable, of course, that in an enormously long interval of geological time, conditions like those in the Black Sea were not continuously persistent. I would assume a 'Nautiloid' mode of life for both *Dactylioceras* and at least those Arietidæ that had not developed a smooth, symmetrical, oxycone shell.

On the east, of course, the Liassic sea terminated against an old land of Palæozoic rocks, now underlying the London Basin, and continuous with the Ardenno-Rhenanian isle farther east. A. de Lapparent[4] and P. Lemoine[5] traced the southern shore-line of this land from Dorset by way of Normandy, where the Lower Lias apparently has not yet been zoned in detail, across to the Ardennes, and Oppel[6] before them stated that his Suabian *tuberculatus* bed agreed, both mineralogically and palæontologically, with that of Avallon (Yonne). From the identity of the micro-fauna of Wurtemberg with that of France, and the fact that the whole of the Lias α, in all its horizons, shows a similarity with that of France, increasing the farther one departs from the eastern and littoral facies of the Suabian Lias, Issler concludes[7] that the Black Forest and the Vosges were covered by the sea. If so, there was a continuous sea from Suabia to Dorset on the one hand, and by way of Franconia and Prussia to Lincolnshire on the other; for the Scunthorpe Ironstone shows great resemblance to the Harzburg Ironstone of North Germany. Issler also assumes that in Wurtemberg the *tuberculatus* bed and succeeding oil-shale indicate a retreat of the sea, already begun in Upper *Coroniceras* times, and the formation of quiet bays of the sea, with abundant crinoids. It may be noted, however, that the appearance of cryptogenous elements preceded that renewed inrush of the sea which brought about the change of facies represented by Lias β.

[1] J. F. Pompeckj, 'Geologische Einflüsse auf die Geschichte des Lebens' Sitz. Ber. Preuss. Akad. Wissensch. vol. xxxiii (1920) p. 686.

[2] 'Das Meer des Kupferschiefers' Branca Festschrift, Leipzig, 1914, p. 481.

[3] B. Hauff, 'Untersuchung der Fossilfundstätten von Holzmaden, &c.' Palæontographica, vol. lxiv (1921) p. 24.

[4] 'Traité de Géologie' 5th ed. (1906) vol. ii, p. 1117.

[5] 'Géologie du Bassin de Paris' 1911, p. 83.

[6] 'Die Juraformation Englands, Frankreichs & des S.W. Deutschlands' Württ. Naturwissensch. Jahresh. vol. xii (1856) p. 167.

[7] 'Beiträge zur Stratigraphie & Mikrofauna des Lias in Schwaben' Palæontographica, vol. lv (1908) pp. 19 & 20.

There appears to be good foundation for Mr. S. S. Buckman's [1] conclusion that dissimilar faunas in general are the results of deposition at different dates. Of course, the same species, in various localities and under different conditions, may undergo alterations in characters and size, and when there is isolation, a stock may develop special local features.

Isolation suggests itself as a cause for a development like *SLATTERITES slatteri* (Wright) (gen. nov., genotype: Natural History Museum, C 6091 = Wright, pl. 1, figs. 1-3, 8), which takes on a broad venter after an oxynote periphery; but the (*oxynotus*) horizon of this form is doubtful, and it is still possible that it may not be of the age of supposed contemporaneous beds in Dorset or Yorkshire. On the other hand, in the *Micraster cor-testudinarium* Chalk of England, ammonites are unknown, whereas they occur in the same Chalk in the North of France; and I have pointed out elsewhere [2] that a study of the distribution and dependence on facies of the two fundamental stocks of ammonites (Lytoceratidæ and Phylloceratidæ) will show that ammonites may have a strictly limited horizontal distribution. Thus, the genera *Ectocentrites* and *Derolytoceras*, from which Deroceratidæ are here considered to be derived, never left the Mediterranean Province; and, since they persisted throughout Lower Liassic times, it is clear that their absence in North-Western Europe cannot be due to 'stratal failure.' For the majority of ammonites, however, difference of facies seems to have little influence on distribution, although it must be remembered that recent nectonic forms with highly-developed organs of locomotion may show less inclination to migrate than benthonic mollusca.[3]

Now, between Dorset and Wurtemberg, deposits corresponding in age with those described in the present paper do occur occasionally, and probably are represented, for example, in the Upper *Gryphæa* Beds of Auxerrois and Morvan, whereas the beds with *Belemnites acutus* of the neighbourhood of Nancy and of Alsace-Lorraine have been correlated by J. A. Stuber [4] with the *tuberculatus* zone in Suabia. In other areas, of course, as, for instance, the neighbourhood of St. Amand (Cher), the fossiliferous zones of the Sinemurian seem to be absent.[5] Failing a continuous sea throughout, there would then have been an archipelago at every emergence and submergence, causing larger unconformities; whereas the local non-sequences and phosphate-beds [6] may be largely due to current-action. Later periods of erosion, however, complicate the picture. It should be noted that even in Wurtemberg,

[1] 'Jurassic Chronology: I—Lias' Q. J. G. S. vol. lxxiii (1917–18) p. 278.

[2] 'On Cretaceous Cephalopoda from Zululand' Ann. S. Afr. Mus. vol. xii (1921) p. 271.

[3] J. Walther, 'Einleitung in die Geologie, &c.' pt. i (1893) p. 190.

[4] 'Obere Abteilung des Unteren Lias in Deutsch-Lothringen' Abhandl. Geol. Spez. Karte von Elsass-Lothringen, vol. v (1893) pp. 174–75.

[5] A. de Lapparent, 'Traité de Géologie' 5th ed. vol. ii (1906) p. 1116.

[6] L. von Werveke, 'Phosphoritzone an der Grenze von Lias α & β, &c.' Mitt. Geol. Landesanst. Elsass-Lothringen, vol. v (1903) p. 347.

the fauna of which country is perhaps better illustrated than that of other regions, only one doubtful form (*Ammonites falcaries olifex* Quenstedt [*pars*]) represents the abundant *Arnioceras* fauna of the period. Faunas so poorly preserved as that of the *tuberculatus*-shales of Wurtemberg have unfortunately not received much attention in the past; but, in order to arrive at a more satisfactory correlation of the Lower Lias deposits in the various areas, it is necessary to collect, with the care and diligence that Dr. Lang has bestowed on the Dorset coast, what (at first) looks like unpromising material.

Part III. Petrology. (By W. A. R.)

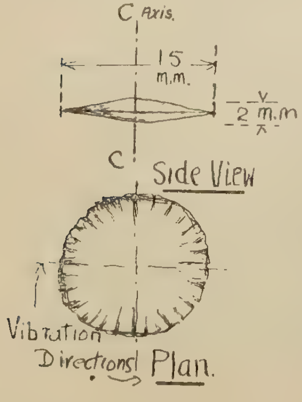
(A) Laminated Shales.

Shales, which are minutely laminated at the outcrop, but appear massive when traced inwards, have been described in Part I (p. 53). The change is accompanied by progressive bleaching towards the weathered surface, and by the deposition of minute, platy crystals of selenite between the laminæ. This bleaching suggests that the development of lamination has been accompanied by a loss of certain constituents of the shales, such as carbon (or hydrocarbons), and also (as indicated by the appearance of gypsum) of iron-sulphide. Thus the weathering of the shales has produced a diminution of volume, and the resulting contraction, by separating the individual laminæ, has revealed the minute internal structure of the shales.

It may be noted that similar development of lamination may be seen, for example, in the Rhætic Black Shales at Beacon Hill, Newark.

(B) The Occurrence of Barytes.

Fig. 3.—*Disc of barytes from bed 71 e, Charmouth.*



In bed 71 *e*, consisting of well-stratified blue shale, Dr. Lang has found thin biconvex discs of a mineral determined by Mr. W. Campbell Smith as barytes. These discs are irregularly distributed along bedding-surfaces, from which they are readily detached, leaving behind a perfect impression of their shape and markings. The general appearance of these barytes discs can be gathered from fig. 3. The largest specimen examined had a mean diameter of 15 mm., a maximum thickness of 2 mm., and the specific gravity = 4·58. Both the upper and lower surfaces of the discs are marked by radial furrows,

very distinct at the thin edge, but faint and often absent in the centre. Microscopic examination shows that this furrowing is superficial, and not due to fibrous structure: for each disc was found to be a simple crystal flattened parallel to (001).

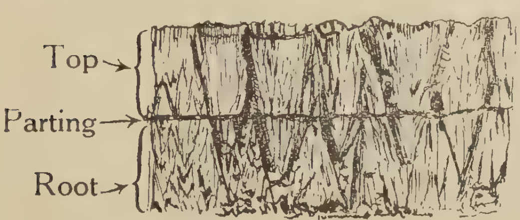
These discs might be contemporaneous nodules, such as the concretions of barytes dredged from recent seas; or secondary segregations of minute traces of barium sulphate in the shales. If, however, growth had progressed freely, it is difficult to understand why either more complete crystal-forms or small spherules did not result. On the other hand, the convex shape and the absence of crystal form in these discs are in accordance with secondary growth against vertical resistance.[1]

(C) The Veins of 'Beef.'

The numerous veins of fibrous calcite, known as 'beef,' are the most striking and interesting feature of the beds, to which they have given a name. In these veins the calcite-fibres pass directly from wall to wall, and they are, therefore, of the type called 'cross-fibre veins.' Moreover, they possess the same general structure as the cross-fibre veins of gypsum and asbestiform minerals, which have been recently described.[2] A continuous plane, marked by inclusions of marls, runs through all the veins, and may be called the parting[3]; and, by analogy with fibrous gypsum, the upper portion of the vein may be conveniently referred to as the top, and the lower as the root (fig. 4).

The parting has been shown (in the papers just quoted) to represent the original fracture of the matrix, from which the crystallizing fibres grew outwards. In the case of 'beef,' fracture and crystallization must have been simultaneous, for the wide horizontal extent covered by a single vein definitely excludes the possibility of the existence of an open crack, even for a short time.

Fig. 4.—*Vein of 'beef,' showing structure and cone-in-cone, Charmouth.*



The veins of 'beef' always occur along a bedding-plane (which they only transgress when passing above or below a calcareous

[1] W. A. Richardson, Geol. Mag. 1921, p. 120.

[2] *Id.* Min. Mag. vol. xix (1920) pp. 77–95; and S. Taber, Trans. Amer. Inst. Min. Eng. vol. lvii (1918) pp. 62–98.

[3] Originally called by Dr. Taber the 'central parting'; but, since it rarely occurs 'centrally' in the veins, the simpler term seems preferable.

nodule), probably because such planes present surfaces of relatively low cohesion. Moreover, the mean direction of the fibres is, in all cases, normal to the bedding-planes. The surfaces of the veins are generally free from marked irregularities, although bed 73 g (described above by Dr. Lang, p. 60) is exceptional, exhibiting coarse projections from its upper surface. There is, indeed, a tendency for some fibres on the upper surfaces to project above the general level; but the lower surfaces of the veins are always smooth.

A single vein rarely has a greater thickness than 2½ inches, and the top is commonly, but by no means invariably, thicker than the root. Where calcareous nodules occur along the same plane as a 'beef'-vein, the latter splits, passing above and below the nodule. Both parts of the vein, however, preserve the normal structure, and possess a parting. The vein below a concretion is thinner than one above, and beneath very large nodules the vein may either die out, or be absent altogether. This behaviour would be explained if feeding solutions were travelling vertically downwards, for big nodules would shelter the region immediately below them.

The calcareous deposits at Charmouth present a remarkable resemblance to the gypsum-beds of East Nottinghamshire. Not only do the fibrous veins exhibit similar structure, but in both localities the veins show the same relation to concretionary nodules. This similarity of behaviour doubtless indicates similarity in the processes of deposition. Accordingly, the following brief statement of the problem of origin is presented, and the reader is referred to an earlier paper of mine for a more detailed discussion of problems common to both the deposits.[1]

(1) Crystallization of calcite-fibres was initiated along a plane of rupture, developed by the conditions of stress prevailing at the time of deposition. The crystal fibres grew outwards in both directions from that plane, a record of which is preserved in the parting.

(2) Fibrous habit suggests rapid crystallization from solutions, which probably became suddenly supersaturated on relief of pressure.

(3) The conditions of stress, which resulted in rupture, can only be referred to a contraction of the deposit under the general desiccation that attended its final consolidation. No open horizontal crack of the extent of these veins could have existed, and crystallization must have kept pace with contraction.

(4) The normal attitude of the fibres to the stratification, the slight upward projection of some top fibres, and the sheltering effect of the nodules on the region immediately below them are points which suggest that the 'beef' crystallized from solutions, the movement of which relative to the matrix was vertically downwards.

With regard to the relative age of the 'beef'-veins, there is the following evidence:—

(*a*) The time of formation of the veins was later than that of the calcareous nodules, as is shown by the splitting of the veins by the nodules, and the sheltering effect that the latter exerted. And, even if the concretions be regarded as contemporaneous with sedimentation, that phase of calcium-carbonate deposition which is represented by the 'beef' is secondary.

(*b*) The 'beef'-veins are earlier than the Lias folding and faulting, for they also are involved in the movements.

[1] Min. Mag. vol. xix (1920) pp. 77–95.

(D) The Cone-in-Cone Structure in the 'Beef.'

Among cross-fibre veins cone-in-cone structure is confined to those in which the mineral is calcite. Moreover, wherever cone-in-cone is found, the material is always fibrous or acicular calcite. The structure is never absent in the 'beef'-veins under discussion. The thinnest veins show the simpler forms, and, as the vein increases in thickness, cone-in-cone structure increases in complexity. Further, a comparison of museum specimens reveals the fact that the big specimens from the Coal Measures and elsewhere are exceedingly complex. So frequently is this relation observed that complexity in the development of cone-in-cone is probably dependent largely on the thickness of the deposit.

Examination of hand-specimens of 'beef' show that the cones themselves pay no regard to the parting (fig. 4, p. 89), but pass without break or deviation from the upper to the lower wall of the vein. There is, moreover, neither faulting on a microscopic scale, nor any kind of displacement of the parting by the cones. On the contrary, the fibres themselves all terminate at the parting, and are never continued across it.

Fig. 5.—*Two types of simple cone-structure in 'beef.'*

The apical angle of the cones varies, but lies generally between 50° and 60°. In the simpler types the cones consist of bundles of fibres, so arranged that they are nearly parallel one to the other and normal to the wall of the vein. In this case the cone-like character is apparently produced by fibres of different length terminating at the outer surfaces of the cones (fig. 5, *a*).

In the larger examples the fibres are notably inclined, tending to arrange themselves parallel to the sides of the cones, in the middle of which the fibres meet, showing a characteristic V-pattern on fractured surfaces (fig. 5, *b*). In still larger examples this mutual inclination of the calcite-fibres is greater, and more intense crowding results in the appearance of smaller conic surfaces within the initial cone, leading to that complex structure aptly described as cone-in-cone.

It should be noted that cone-in-cone is not especially associated with, or developed in, zones where the strata have been disturbed. But the effects of crushing are not uncommon in veins from such

situations, and are easily recognizable. The veins may be fractured, often along the conic surfaces, and in folds the fibres may be bent in such a way that the ends of the top fibres point up the dip.

When examined microscopically, the calcite-fibres have bluntly-pointed terminations, and are rudely circular in cross-section, for crystal faces are rarely if ever developed (fig. 6). In convergent light cross-sections show the emergence of the optic axis, indicating that the fibres are elongated in the direction of the vertical axis, as is usual in fibrous calcite.[1] The mean angle at the pointed ends of the fibres is nearly equal to that between the rhombohedral cleavages of calcite, and the close relation between the fusiform shape of the fibres and this cleavage is sketched in fig. 7. Opaque

Fig. 6.—*Thin section of 'beef,' Charmouth; × 50.*

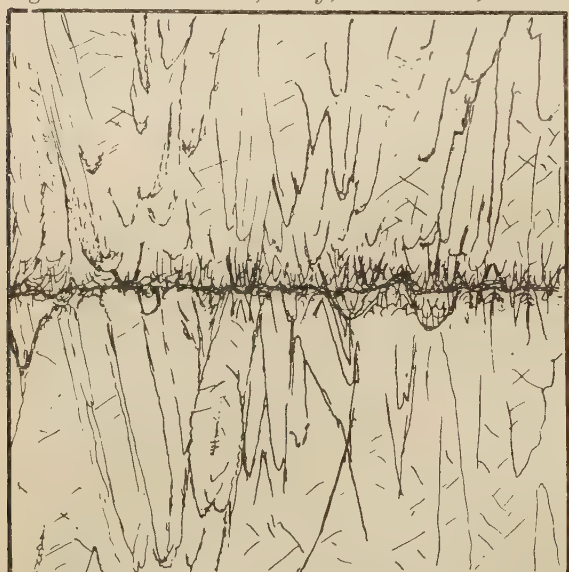


Fig. 7.—*Sketch of single calcite-fibre, showing fusiform shape and rhombohedral cleavage. × 50.*

particles of marl are sporadically distributed throughout the slide, but there is no sign of sheaths of marl surrounding the fibres or separating the cones. At the parting there is a certain amount of granulation, doubtless the result of external pressures. No optical sign of strain was observed, and even the glide-planes parallel to *e* (110) rarely appear.

Cone-in-cone structure has engaged the attention of many workers. H. C. Sorby[2] compared cone-in-cone with oolitic structure, and considered that the former was produced by radial

[1] L. J. Spencer, Min. Mag. vol. xi (1896) pp. 184–87.

[2] Rep. Brit. Assoc. (Aberdeen, 1859) pt. 2, p. 124; and 'The Geologist' vol. ii (1859) p. 485.

crystallization around an axis, instead of a point as in the latter. Of this arrangement, however, the cones in 'beef' show no sign. O. C. Marsh[1] considered growth-pressure as the chief factor. Prof. J. A. G. Cole[2] rejected this view, and adhered to that of Sorby, remarking that 'the so-called beef . . . forms the best link I am acquainted with between cone-in-cone and ordinary fibrous crystallization' (*op. cit.* p. 140). Prof. T. G. Bonney[3] allowed a greater part to the mechanical element, and considered contraction following crystallization to be an essential cause. Finally, O. M. Reis[4] dealt with the subject at great length. He considered that long-continued concretionary crystallization of calcium-carbonate solutions in argillaceous strata, under some pressure and aided by decaying organic matter, is the principal condition. Contraction, re-solution, and deposition help in the production of some of the complex effects.

Now, cone-in-cone is evidently a primary structure in 'beef'-veins, and not the result of forces that disturbed the strata. Occasionally, fossil shells may be found along the parting; but there is nothing to indicate that exceptionally complex structures are associated with richness of organic remains. Moreover, the fibrous character of 'beef' suggests rapid, not 'long-continued' crystallization; and, finally, the close packing and the mutual interference of the fibres during growth are evidence that contraction cannot have taken place.

There seem to be only three essential facts bearing on the origin of cone-in-cone structure: namely, (i) its limitation to fibrous or acicular calcite; (ii) the direct increase of complexity with thickness; and (iii) the penetration of a 'beef'-vein as a whole by the cones, with a total disregard of the internal structure. I shall endeavour to show that the sensitiveness of the calcite-fibres to shear-stresses set up during their crystallization is responsible for these peculiarities.

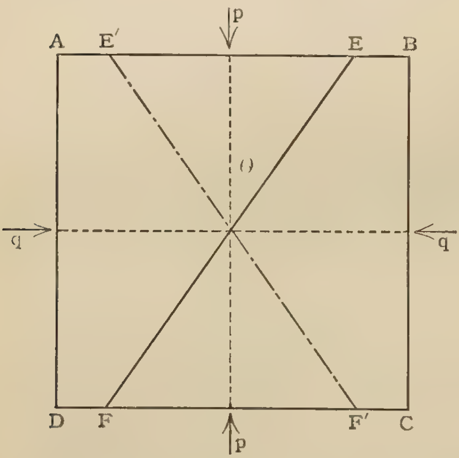
In the first place, it is apparent that during crystallization the 'beef'-veins must have supported a load equal to the weight transmitted by the overlying deposit, less the tensile stresses originating through desiccation. If, now, the stability of an element from the middle of a growing 'beef'-vein be considered, this load will produce a principal (vertical) stress p acting on the top and bottom faces of the element (fig. 8, p. 94). In addition, there will be two equal principal (horizontal) stresses q acting on the vertical faces of the element, and generated by the resistance to lateral growth set up by the crowding of the fibres. (Only one of these principal stresses appears in the figure, for the other acts normally to the plane of the paper.) Now, stress on any plane inclined to the principal stresses is oblique, and there is some

[1] Proc. Amer. Assoc. Sci. 1867.
[2] Min. Mag. vol. x (1892) pp. 136–41.
[3] *Ibid.* vol. xi (1895) pp. 24–27.
[4] Geognostische Jahreshefte, 1902 (1903) p. 250.

plane (let it be EF) on which the stress is most oblique, or, in other words, along which the shearing stress is a maximum.[1] Further, symmetry requires that there shall be another plane of maximum shear, E′, F′ in the figure. In three dimensions there will be surfaces of maximum shear, either pyramidal or conical, according as the specimen is cubical or cylindrical. Under similar conditions of loading, homogeneous test-cubes of Portland cement break into six pyramids meeting with their apices at the centre of the test-cube, and such broken test-pieces may be compared with cone-in-cone concretions described by C. A. White,[2] in which all the cones radiated from a centre, with their apices all pointing towards that centre.

In applying such an analysis to explain cone-in-cone, we are probably not concerned with mechanical deformation (since there is no optical sign of strain), but with the influence of the state of stress on the course of crystallization. The inclination of the perfect rhombohedral cleavage to the vertical must make the calcite-fibres extraordinarily sensitive to the influence of the shear. Where master shear-planes were established, fibres already formed might be fractured; but, more probably, the action would be to inhibit growth in such a way that the fibre could not cross such a plane. The actual spacing of the planes set up would be influenced by many factors, but chiefly by boundary conditions. The appearance of secondary surfaces within the more prominent surfaces is sometimes seen when slabs, instead of cubes, are used as test-specimens. And, therefore, the establishment of cones within cones would be due to the formation of new shear-surfaces as thickness increased.

Fig. 8.—*Element from a growing 'beef'-vein subjected to principal stresses* p *&* q.



By way of comparison, it is interesting to note that the extreme tenuity of asbestos-fibres has been correctly explained by the combination of prismatic growth with perfect prismatic cleavage, and the platy character of satin-spar by the presence of the perfect brachypinacoidal cleavage. Thus all cross-fibre veins have

[1] A. Morley, 'Strength of Materials' London, 1908, p. 14.
[2] Amer. Journ. Sci. ser. 2, vol. xlv (1868) p. 401.

the same general structure and origin, while their peculiarities can be traced to the crystallographic characters of the minerals present.

(E) The Calcareous Nodules.

The chief problem presented by the occurrence of calcareous nodules (‘cement-stones’) in the Shales-with-‘Beef’ is the determination of their age relatively to the sediments. The significance of the evidence has been discussed elsewhere,[1] and it is only necessary to collect the clues that these deposits furnish as to their own age.

Conformable disturbance of the strata is frequently observed. This has been shown, on experimental grounds, to be consistent with either primary or secondary age, and recently has been reported over fossil remains.[2] As a criterion of relative age it is, therefore, useless.

The nodules have the flattened ellipsoidal shape suggestive of secondary origin. Septarian structure is common: a feature due to the drying of a colloidal centre.[3] This structure is not confined to nodules of secondary origin, and is no indicator of relative age.

While the nodules are sometimes fossiliferous, they are more frequently non-fossiliferous, and are distributed quite regardless of the location of fossils. Lignite is an occasional inclusion, and two types are found: one of a woody character, and the other black, resembling jet, but very brittle and showing septarian fractures. Plant-remains within the nodules, however, are in the same state of preservation as those found in the shales. It may, therefore, be concluded that nodular segregation occurred when the principal stages in the decay of vegetable matter were completed. It will be recalled that Dr. Marie Stopes[4] proved the contemporaneous age of coal-balls conversely by the more perfect preservation of included plant-tissues.

In considering evidence of the distribution of the nodules, the enquiry must be extended more widely than the particular levels with which this paper is more intimately concerned. Completely measured sections of the Dorset Lias are given by H. B. Woodward,[5] and on these the distribution suggested below is based.

The characteristics of the vertical distribution of the limestones and nodular lines are set out in the diagrams of fig. 9, p. 96. In the curve on the right the intervals between lines are plotted against their position above the base of the Lias. The same

[1] W. A. Richardson, Geol. Mag. 1921, p. 120.

[2] H. L. Hawkins, *ibid.* p. 192.

[3] W. A. Richardson, ‘On the Origin of Septarian Structure’ Min. Mag. vol. xviii (1919) pp. 327–38.

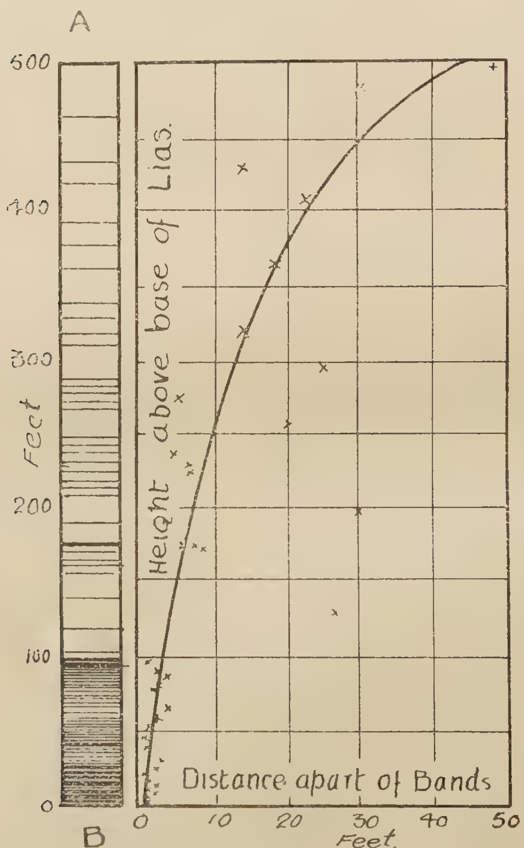
[4] M. C. Stopes & D. M. S. Watson, Phil. Trans. Roy. Soc. ser. B, vol. cc (1909) p. 167.

[5] ‘The Jurassic Rocks of Britain, vol. iii: the Lias of England & Wales’ Mem. Geol. Surv. 1893, pp. 57 *et seqq.*, 195 *et seqq.*

facts of distribution are shown in the vertical section AB, on the left of fig. 9. This section is, however, diagrammatic, for only sufficient bands could be inserted to show the relative distribution.

If the curve and the section be compared with those for Cretaceous flint or Liesegang gels,[1] it will be seen that the limestone

Fig. 9.—*Vertical distribution of nodular limestone in the Lias of Dorset.*



distribution is of the same type. The rhythm may be analysed as follows:—

(1) In the lower 100 feet, the mean separation of bands is 1 foot, and the maximum 3 feet.

(2) The next 200 feet show (in one case only) a minimum interval of 4 feet, and a mean of about 10.

(3) In the remaining 300 feet to the top of the Middle Lias, the minimum separation is 12 feet, and the mean about 20 feet.

[1] W. A. Richardson, Geol. Mag. 1919, p. 541.

Thus the deposit exhibits the characteristics of rhythmic precipitation. There is a region of close deposition, followed by gradually increasing separation of bands to the top of the Middle Lias, above which the occurrence of nodular limestones is not recorded.

Dr. Lang has drawn my attention to the palæontological evidence of the existence of non-sequences[1] that are not insignificant, and point either to extensive thinning or to contemporaneous erosion of many feet of strata, which might include limestone-bands. It is obviously a question of the first importance to decide whether or no the limestone suite is intact. The available evidence is not very complete; but two reasons may be given for considering that the full rhythm is present, and has not been affected by non-sequences.

In the first place, it is scarcely possible that beds of dense limestone should be contemporaneously eroded, without originating coarse beds containing limestone-pebbles situated within a reasonably short distance of the original site. But there is no record of such pebbles.

In the second place, it is found that the horizontal distribution of the limestone-nodules corresponds to the vertical. In the lower levels continuous tabular bands of limestone, often showing nodular structure, or passing laterally into dense rows of nodules, are common. Higher in the sequence tabular bands disappear, and close nodular lines are characteristic; and, as the vertical interval between the beds increases, so also does the horizontal distance separating the individual nodules of a bed. Therefore, the same rhythmic sequence is obtained, whether the horizontal or the vertical relations are studied. And, since there are no signs of successive independent rhythms, it must be concluded that the limestone suite is the product of one process of rhythmic deposition, not only secondary, but apparently later in date than any contemporaneous erosion that may have affected any portion of the deposits.

One further point must be mentioned. In places occur 'indurated bands' of hard calcareous marl. These are not regarded as part of the limestone suite, because all members of the latter show clear lines of nodular origin and largely displace the marls; whereas the indurated bands are shales impregnated with, or cemented by carbonates, and may be regarded as a distinct, perhaps final phase of the deposition of calcium carbonate at a stage (later than the 'beef') when any solution remaining in the sediment finally dried.

(F) Sedimentary History of the Beds.

I venture, in conclusion, to suggest an outline of the sedimentary history of these beds in stages based on the preceding study:—

(1) Sedimentation, during which contemporaneous erosion may

[1] Prominently advocated for the Lias generally by Mr. S. S. Buckman, Q. J. G. S. vol. lxxiii (1917–18) pp. 257–78: see especially figs. A & B, pp. 265, 272.

have taken place locally, while calcareous matter gradually dissolved in the water-logged deposits.

(2) Initial desiccation, possibly inaugurated or accompanied by some elevation causing a motion of the solutions relatively downwards.

(3) Rhythmic precipitation of the concretionary limestone suite.

(4) Stage of maximum desiccation. Regions, or levels, of low pressure produced by contraction, along which supersaturated solutions rapidly deposit veins of fibrous calcite (beef).

(5) Desiccation and consolidation completed, with the precipitation of any residual solutions which cemented and hardened the marls.

(6) The strata, including the concretionary deposits, faulted and folded by earth-movements.

Discussion.

Dr. F. A. Bather said that, if Mr. Richardson were right, the more obvious lithological character of the section could not have influenced the succession of life. What, then, was the cause of the repetition of faunas? To answer that question we needed better knowledge of the habits of ammonites, and we needed to trace their migrations by equally careful collecting in other areas. But a knowledge of ammonites would not suffice; we must study the other elements of the fauna (the flora was presumably beyond reach). The researches of the Danish Biological Station showed that similar faunal changes were taking place now, and that they were frequently initiated by a disturbance of equilibrium in the food-constituents of the life-assemblage. Those researches should be studied by all who would solve these problems of stratigraphical palæontology.

Mr. G. H. Plymen enquired whether Mr. Richardson found it possible to extend the application of the theory of precipitation by diffusion, to the deposition of the 'beef'-beds and similar gypsum sheets; whether Liesegang's experiment might be considered on a large scale, where calcareous waters overlying shales containing sulphates would give banded precipitation of calcium sulphate. These sheets then became contemporaneous, regardless of horizon.

Prof. A. Hubert Cox remarked that lithological types similar to those described by the Authors were well developed in the Lower Lias along the Glamorgan coast. Individual bedding-planes were stripped bare over wide areas along the shore, and exceptional opportunities for their study were thus afforded. The upper surfaces of the various limestone-bands presented certain remarkable contrasts. Some of the surfaces had a persistent table-like smoothness. Other bands of apparently identical lithology showed very uneven surfaces, as if the beds were made up of masses of irregular nodules. Despite the uneven surface, the boundary between limestone and shale was quite sharp. His explanation of the differences in the character of the limestone-

surfaces was that the limestones represent precipitates of calcite-mud derived by the degradation of Carboniferous Limestone areas. The exact character of each precipitate varied according to slight changes in the salinity of the waters. Similar results could be obtained by the slow precipitation of clay-suspensions under the influence of electrolytes. The speaker had not yet had an opportunity of trying similar experiments with calcite-suspensions, but he had little doubt that under suitable conditions similar effects could be brought about.

Miss C. A. RAISIN asked whether, from the study of the interesting cone-in-cone structure in Jurassic strata, Mr. Richardson considered there was any evidence that contraction due to the drying of the material had acted as a partial cause, in conjunction with crystallization and the other forces indicated.

Dr. LANG thanked the Fellows for their reception of the paper, and, in reply to Dr. Bather, mentioned that he had collected many lamellibranchs and other fossils from the Shales-with-'Beef,' but had not found a specialist to name any, except the ammonites; he had, therefore, recorded in his paper but few fossils besides ammonites. As to faunal repetition, if we could trace our restricted horizons laterally, we should undoubtedly discover the intermediate histories of the temporarily eclipsed genera. Two possibilities were suggested:—(1) The reappearing form might not really be closely related to the vanished form—the supposed genus might be polyphyletic. (2) The discontinuous succession of the forms of a given genus in one locality might be the result of a periodic outpouring of allied forms from a more or less distant centre. If we could find such a centre, we should see that there the vertical distribution of the genus in question was continuous.

Mr. W. A. RICHARDSON said that it was very difficult, in the present state of knowledge. to fix the exact date of nodular formation; but it occurred at Charmouth before the crushing of the ammonites, and probably while the sediment was still comparatively loose. In reply to Prof. Cox it might be pointed out that the same peculiar rhythm occurs in many nodular deposits (such as flint and gypsum), and it was the difficulty of finding any external cause varying in this way that supplied the chief reason for resorting to an 'inner,' that was, a physical-chemical cause. Regarding Mr. Plymen's query, the bands were formed simultaneously, only in the sense that they were the result of one continuous process of precipitation. There would not be much scope for contraction as a cause of cone-in-cone, as suggested by Miss Raisin, for the material was deposited initially and continuously in crystalline form.

4. *On the* Geological Importance *of the* Primitive Reptilian Fauna *in the* Uppermost Cretaceous *of* Hungary; *with a* Description *of a* New Tortoise (*Kallokibotion*). By Baron Francis Nopcsa, For. Corresp. G.S. (Read March 8th, 1922.)

Contents.

I. The Age of the Reptiliferous Strata.

In Eastern Hungary[1] the Upper Cretaceous can be divided into two horizons with an unconformity between them (53, 66).[2] The lowest deposits in some places, as near Szászcsor (53), are red conglomerates; in other places (as, for example, Ohaba Ponor) they are red laterites filling fissures in the Tithonian limestone (28). Then follow, extending farther than the red deposits, grey marls and sandstones containing at their base seams of coal (28), and somewhat higher up several ammonites, such as:

Acanthoceras newboldi Kossmat.
A. cenomanense Pictet.
A. harpax Stoliczka.
A. rhotomagense (Defrance).
Acanthoceras mantelli (Sowerby).
A. morpheus Stoliczka.
Puzosia planulata (Sowerby).
Crioceras sp. (53).

These help to fix the age of the marls as Cenomanian. Overlying the ammonitiferous strata are coarser sandstones, crammed with enormous numbers of *Actæonella* sp. (28, 53); then come marls and sandstones containing some rare examples of *Actæonella gigantea* (53), attaining a diameter of 6 inches and more; and lastly, a great complex of rough blue and white sandstones is met with (7), corresponding to the Emscher Sandstone of German geologists or to the zone of *Micraster cor-anguinum* in England. These strata are characterized throughout Transylvania by remarkably large *Inocerami* (53, 65). In *Inoceramus giganteus* Pálfy, for example, each valve attained a length of nearly 2 feet (65).

[1] Under the term Hungary, not the area politically so defined is meant, but that basin which since Upper Senonian times has had for its rim the range of the Carpathians.

[2] Numerals in parentheses refer throughout to the Bibliography, § VI, p. 113.

Unconformably upon these beds rest younger marine layers containing *Pachydiscus neubergicus* Hauer, *P. colligatus* Binck, *Scaphites constrictus* Sowerby (53), and numerous bivalves and gasteropods (51, 64), among which it is sufficient to mention *Melanopsis galloprovincialis* Matheron and *Pyrgulifera pichleri* M. Hœrnes.

All the fossils, a more complete list of which is given below,[1] prove that these younger marine strata belong to the Upper Senonian (Campanian). They pass upwards into strata wherein brackish-water forms predominate, such as *Cerithium*, *Melanopsis*,

[1] The complete list for Puj is:—

Baculites fuchsi Redtenberg.
Scaphites cf. *constrictus* (Sowerby).
Fusus lineolatus Zekeli.
Avellana hugardiana A. d'Orbigny.
Dentalium nudum Zekeli.
Pecten cretosus Defrance.
Pecten virgatus Nils.
Gervillia solenoides Defrance.
Pinna cretacea Schlotheim.
Exogyra matheroniana A. d'Orbigny.
Modiola capitata Zittel.
Cucullæa bifasciculata Matheron.
Limopsis calvus Sowerby.
Trigonia scabra Lamarck.
Cardium productum Sowerby.
Circe discus Matheron.
Pholadomya granulosa Zittel.

For Alvincz the list is:—

Exogyra ostracina Lamarck.
Anomia pellucida Müller.
Anomia coquandi Zittel.
Ostrea pseudo-madelungi Pálfy.
Lima divaricata Dujardin.
Lima tecta Goldfuss.
Pecten krenneri Pethö.
Pecten lævis Nils.
Psammobia suessi Zittel.
Inoceramus crippsi Mantell.
Septifer lineatus Sowerby.
Modiola flagellata Pálfy.
Gervillia solenoides Defrance.
Lithophagus alpinus Zittel.
Pinna cretacea Schlotheim.
Cucullæa transylvanica Pálfy.
Leda tenuirostris Reuss.
Astarte similis Münster.
Astarte hemiornata Pálfy.
Crassatella macrodonta Sowerby.
Crassatella supracretacea Pálfy.
Cardium gosaviense Zittel.
Cardium duclouxi Vidal.
Cyprimeria aff. *concentrica* Zittel.
Cyprimeria discus Matheron.
Corbula lineata Müller.
Turritella cf. *alternans* Römer.
Glauconia obvoluta Schlotheim.
Transylvanites semseyi Pálfy.
Cerithium kochi Pálfy.
Chemnitzia acutissima Pálfy.
Chemnitzia cf. *turrita* Zekeli.
Pyrgulifera aff. *böckhi* Pálfy.
Natica alkemyerensis Pálfy.
Natica bulbiformis Sowerby.
Volutilithes latisepta Schlotheim
Cheilostoma winkleri Münster.
Aporrhais schlotheimi Römer.
Aporrhais calcarata.
Ovula striata Zekeli.
Ringicula hagenowi Müller.
Cylichna aff. *mülleri* Bosq.
Actæonella gigantea Sowerby.

At Alkenyér, one may mention, besides some species known at Alvincz:—

Cylichna ornamentata Pálfy.
Mitra cancellata Sowerby.
Mitra zekeli Pictet & Campiche.
Cerithium millegranum Münster.
Natica transylvanica Pálfy.
Natica klipsteini Müller.
Laxispira cochleiformis Müller.
Turritella kochi Pálfy.
Turritella cf. *acanthophora* Römer.
Volutilithes septemcostata Forbes.
Trochus gemmeus Müller.
Liotia macrostoma Müller.
Vola quadricostata Sowerby.
Leda supracretacea Pálfy.
Leda complanata Pálfy.
Leda cf. *försteri* Müller.
Crassatella minima Pálfy.

and *Pyrgulifera.* Among the bivalves, *Cyrena dacica* Pálfy may be specially mentioned.[1]

At both localities where these brackish-water beds are known, at Puj and Alvincz, they gradually pass upwards into freshwater deposits containing much-crushed (and therefore undeterminable) gasteropods, very rarely a *Unio*-like bivalve, and numerous well-preserved remains of various vertebrates. In the north of Transylvania, where, until recently, but few vertebrate remains were found, Anton Koch (36) determined in a freshwater limestone intercalated in these beds the following gasteropoda:—

Planorbis aff. *elegans* F. Edw.
Paludina aff. *globuloides* Forbes.
Limnea aff. *michelini* Deshayes.
Limnea aff. *arundaria* Brand.
Limnea aff. *inflata* Brongniart.

It is evident that not a single species has been determined in such a manner as to be of stratigraphical value. Since the brackish-water deposits correspond to the upper part of the French Garumnian, or to the limestone of Faxö in Denmark, the freshwater beds must be considered as an equivalent of the uppermost layers containing *Nautilus danicus* of Northern Europe. It is of great importance to be assured that there can be no doubt about their age. Near Demsus (Csula) the freshwater beds enclose a great rolled block of limestone containing *Actæonella.*

Curiously enough, the foraminifera, discovered by Halaváts at Szászsebes in a rolled block of limestone (coming from the conglomerates that are intercalated among the Dinosaur-bearing sandstones), have a very Kainozoic aspect. L. Lóczy (42) determined these foraminifera, and found:

Orbitolites sp. cf. *complanata* Lamarck.
Alveolina sphærica Fort, var. *haueri* A. d'Orbigny.
A. cf. *elongata* A. d'Orbigny.
Alveolina cf. *ovoidea* A. d'Orbigny.
A. aff. *oblonga* A. d'Orbigny.
Peneroplis sp.

Since the Kainozoic facies holds good also for the freshwater shells mentioned above, everything goes to show that the Dinosaurian beds of Transylvania extend to the very dawn of the Eocene, and perhaps even include its basement-deposits.

The thickness of the Danian deposits of Transylvania, built up of blue and purple clays, red, yellow, blue, and greenish sandstones, and mottled conglomerates, varies according to the different

[1] The complete list for Alvincz is:—

Cerithium hœninghausi Keferstein.
Cerithium herepeyi Pálfy.
Cerithium alvincziense Pálfy.
Cerithium kochi Pálfy.
Cerithium loczyi Pálfy.
Cerithium apulumium Pálfy.
Melanopsis crassatina Vidal.
Melanopsis cf. *galloprovincialis* Matheron.
Melanopsis avellana Sandberger.
Hemisinus ornatus Pálfy.
Hemisinus pulchellus Pálfy.
Transylvanites semseyi Pálfy.
Pyrgulifera böckhi Pálfy.
Pyrgulifera decussata Pálfy.
Dejanira bicarinata Zekeli.
Nerita spinosa Pálfy.
Nerita granulata Pálfy.
Turritella hagenowiana Münster.
Glauconia obvoluta Schlotheim.
Actæonella gigantea Sowerby.
Cyrena dacica Pálfy.

regions, but is always very great. In the north of Transylvania, where a band of freshwater limestone is intercalated near the top of the Danian, it attains some 3700 to 4500 feet in thickness (36); on the western margin of the Transylvanian basin, where the Danian rests in some places transgressively on the crystalline rocks forming the rim of that basin, its thickness is but 900 feet (36); in Southern Transylvania it attains (in a geosyncline at the northern base of the Transylvanian Alps) a thickness of at least 6000 feet (53). At many places in Transylvania, especially in the north and east, the Danian is covered by Middle Eocene strata (36); in the south, however, in the neighbourhood of Hátszeg, the Middle Eocene is missing, and younger Kainozoic (Miocene and Upper Oligocene layers) rest upon it (21, 53).

II. The Vertebrate Fauna.

From several good exposures in the country round Hátszeg numerous vertebrate remains were collected, and, although a detailed study will probably bring to light further quite interesting features, the most important characters of the fauna can already be fixed.

This fauna comprises Pterosauria, birds, tortoises, crocodiles, and several Dinosaurs (37). The birds, tortoises, crocodiles, and some of the Dinosaurs, such as *Titanosaurus*, *Orthomerus*, and *Rhabdodon*, seem to have lived in marshes and lakes in the deposits of which they are found. The Pterosaurians and some other Dinosaurs (such as *Struthiosaurus* and '*Megalosaurus*') became accidentally buried in these sediments (53).

Unfortunately, the bird-remains (1) and those of the Theropoda (59) are in so poor a state of preservation that they do not throw much light on the systematic position of the animals to which they belonged, and the same statement holds good for the Pterosaurs; the latter seem, however, to be related to the Ornithocheiridæ, especially to *Ornithodesmus* (74). They are, therefore, more primitive than the American Pteranodontidæ.

The crocodilian remains are better preserved than the remains of the animals hitherto mentioned (59), for in the Földtani Intézet (Hungarian Geological Institute) at Budapest a nearly complete skeleton is preserved, which will prove to be, when mounted, the finest known skeleton of a true Mesozoic crocodilian (69, 70, 73). Preliminary study, however, has failed to reveal any remarkable features by which this animal differs from existing forms. Perhaps it represents a new genus, but otherwise this specimen seems to be of little palæontological importance. It is identical with *Crocodilus affuvelensis* Matheron (50). In contrast to this, the Dinosaurs and tortoises of the Transylvanian Cretaceous exhibit many remarkable features. In order to show these features clearly, the representatives of each group must be considered separately, and I think it advisable to begin with the tortoises.

(A) KALLOKIBOTION BAJAZIDI, gen. et sp. nov.

This new genus is represented by several specimens; with the exception of a few, they are preserved in the British Museum (Natural History). In one the plastron and the nearly entire impression of the carapace, as well as a natural cast of the body-cavity, are splendidly preserved. A second individual shows the disintegrated and somewhat crushed carapace, parts of the plastron, and a fairly well-preserved skull. A third shows a well-preserved but laterally somewhat crushed carapace from above, the entire pelvic girdle, the cervical and caudal vertebræ, and some limb-bones. Yet another specimen has a badly-preserved skull, isolated cervical and caudal vertebræ, limb-bones, and shows the dorsal vertebræ from the interior. Other specimens of minor importance show parts of the scapular arch, limb-bones, parts of the pelvis, and so on. It is evident that practically the whole of the skeleton is known; but, since the detailed description is to be published elsewhere,[1] only the principal traits of this interesting genus will be mentioned here. The skull is completely roofed over like in *Baena sima* (30). The cervical vertebræ show strong lateral processes, and resemble in outline those of *Chisternon hebraicum* (30); they are, however, deeply biconcave in all specimens. The caudal vertebræ are strong and biplane, and show that the tail was well-developed. The carapace shows well-developed neural bones and vertebræ, very broad dorsal scutes, small costal and marginal scutes, but no supernumerary scutes such as occur in *Baena*, *Thescelus*, *Boremys*, *Platychelys*, and other primitive tortoises (30). The posterior margin of the carapace is moderately scalloped; on the plastron one can distinguish a well-developed mesoplastron reaching to the middle line of the body, and several inguinal scutes. In the interior may be discerned on the carapace two marked tuberosities for the attachment of the superior ends of the scapulæ, and on the plastron tuberosities for the attachment of the pubes and ischia. Scapula, proscapular process, and coracoids are all rod-like; the glenoidal fossa is well marked and very deep; the prepubic process is ossified, as in *Chisternon hebraicum* (30) and *Orlitsia*; the ischia unite by a broad and deep symphysis which forms a vertical wall, showing in the middle a convexity directed forward, and resemble thus the ischia of *Orlitsia*. The femur and humerus are dilated at both ends, and show remarkably well-defined and smooth surfaces for articulation. The toes ended in well-developed claws.

The nearest European relatives of *Kallokibotion* seem to be *Plesiochelys* and *Pleurosternon*, which are abundant in the Wealden Beds (2, 48, 78). Among the American Amphichelydæ, only *Glyptops* is known to possess biconcave vertebræ; and this genus, although lasting perhaps until the end of the Cretaceous Period, shows a maximum of development in the Niobrara phase (30).

[1] F. Nopcsa, '*Kallokibotion*, a Primitive Amphichelydean Tortoise' Palæontologia Hungarica, vol. i, Budapest, 1923 (in the press).

Thus the primitive *Kallokibotion* surviving into the Danian would appear to be a remnant of an otherwise extinct fauna.

(B) RHABDODON PRISCUM Matheron (50).

[Synonyms: *Mochlodon suessi* Seeley (73); *Ornithomerus gracilis* Seeley (73); and *Mochlodon suessi* var. *robustum* Nopcsa (52); the last-named and the type of Matheron's genus and species are probably females, while *Ornithomerus* is a young specimen.]

This Orthopodous Dinosaur is closely related to the American *Camptosaurus* from the Jurassic (32), *Kangnasaurus* from the Cretaceous (?),[1] and *Thescelesaurus* from the Lance formation (23). In Europe *Camptosaurus* occurs in the Kimmeridge Clay (48) and in the Oxford Clay (47). Compared with the European *Iguanodon*, which evidently once passed through a Camptosaur-like stage of evolution, *Rhabdodon* seems more primitive, because of the small number of alveoli, and because the mandibular teeth had only one principal ridge and not two. Primitive characters also are the biplane cervical vertebræ, the *Hypsilophodon*-like lack of an expansion on the dorsal ribs (33), the feeble development of the preacetabular part of the ilium, of the pseudopectineal process, and the direction of the fourth trochanter. As in *Camptosaurus*, the ischium is hammer-shaped in the males. It must be mentioned, as a sign of specialization, that the ischium shows no projection forming the inferior border of the foramen obturatorium.

If we consider that in Belgium, by the time of the Upper Senonian, the *Iguanodon* of the Wealden had changed to the genus *Craspedodon* (19), and that the *Camptosaurus* stage of *Iguanodon* has to be sought for in earlier beds than the Wealden, the survival of a modified Camptosaurian at the end of Danian times is quite a noteworthy feature.

(C) ORTHOMERUS TRANSYLVANICUS Nopcsa.

[Generic synonyms: *Limnosaurus* Nopcsa *non* Marsh (52); *Hecatosaurus* B. Brown (8); *Telmatosaurus* Nopcsa (55); male and female distinguishable by the shape of the base of the centra of the caudal vertebræ, one sex (it is uncertain which) showing a furrow (60, 61).]

Orthomerus belongs with *Kritosaurus* (8) to the Protrachodontidæ, or primitive *Trachodon* group; it is, however, even more primitive than its American relative. Both these Protrachodontidæ differ from the true Trachodontidæ, in that the anteorbital part of the skull is not so long as in the latter (9, 10, 32, 39).

Orthomerus differs from *Kritosaurus* in the leaf-like asymmetrical shape of the mandibular teeth, which are not compressed antero-posteriorly, but in a linguo-labial direction, and they lack the projecting ridge characteristic of the Trachodontidæ. The mandibular teeth of *Orthomerus* approach in these points strongly to

[1] S. H. Haughton, 'On some Dinosaur Remains from Bushmanland' Trans. Roy. Soc. S. Africa, vol. v (1915–16) p. 259.

the hypothetical shape of teeth which must have given rise to the highly ornamented teeth of the Kalodontidæ on one side, and to the teeth of the true Trachodontidæ on the other. To a certain extent, they resemble the teeth of the Ceratopsian genus *Brachyceratops* (24). The number of teeth is in *Orthomerus* smaller than in *Kritosaurus*. Although not great in number, these three features are quite sufficient to fix the primitive nature of *Orthomerus*, the skeleton of which has not yet been thoroughly studied.

Since the Trachodontidæ occur throughout the whole of the North American Upper Cretaceous, and since they must have been derived from an *Orthomerus*-like type, the occurrence of a *Protrachodon* at the end of the Cretaceous Period in Europe is again an atavistic trait.

(D) STRUTHIOSAURUS TRANSYLVANICUS Nopcsa (59).

[Generic synonyms: *Cratæomus* Seeley (73); *Pleuropeltus* Seeley (73); *Rhadinosaurus* Seeley *partim* (73); *Danubiosaurus* Bunzel (13); *Leipsanosaurus* Nopcsa ? (63); of the species *Struthiosaurus lepidophorus* the female has been described as *S. pawlowitchi* (58); the sex of *S. transylvanicus* has not yet been determined.]

So far as can be seen at present, *Struthiosaurus* is a relative of *Stegoceras* of the Belly River formation (40), of *Nodosaurus* of the Benton (44), and of *Polacanthus* (56) of the Wealden. Another relative of *Struthiosaurus* is the imperfectly-known *Acanthopholis* of the Cambridge Greensand (71). On comparing *Struthiosaurus* with *Stegoceras*, it can be seen that in the latter the backward direction of the condyles is more marked, the skull-bones are thicker, the pittings on the surface are more distinct than in *Struthiosaurus*, and the upper surface of the skull projects farther backward; but otherwise the two genera seem to agree very closely. The dorsal vertebræ of *Struthiosaurus* approximate to those of *Polacanthus* (56); the anterior dorsal ribs show the same symmetrical T-shaped section as in all Thyreophora,[1] and differ in shape and function from the asymmetrically T-shaped and bird-like anterior dorsal ribs of the higher Orthopodous Dinosaurs; the posterior dorsal ribs of *Struthiosaurus* show a tortoise-like lateral expansion, but are not blended together as in *Polacanthus*. The segmented armour of *Nodosaurus* (44) suggests the probability that here a similar structure may be expected in the lumbar region. The femur of *Struthiosaurus* agrees with the femur of *Polacanthus* (56) and *Nodosaurus* (44), but better still with the European *Cryptosaurus* from the Oxford Clay (47). The dermal armour is thinner than in *Polacanthus* or *Hierosaurus*. Summarizing all the characters that we have been considering, it is well nigh certain that *Struthiosaurus* is a type from which (to some extent) *Polacanthus* could be derived, but not *vice versa*. The bird-like shape of the basis cranii

[1] This term (58) was proposed in 1915 to comprise all the armoured Dinosaurs: namely, Stegosauridæ, Acanthopholidæ, and Ceratopsidæ.

without tubera basioccipitalia, and with the condyles directed downward, and the relatively large brain-case are likewise primitive features, since they are handed down from the bipedal ancestor of the Thyreophora (62). For an animal living at the end of the Cretaceous Period these primitive features are quite remarkable.

(E) Titanosaurus dacus Nopcsa.

As R. S. Lull has pointed out (43) already, the mere occurrence of a Sauropodous Dinosaur at the very end of the Cretaceous is in itself an anachronism. The genus *Titanosaurus* is well known from the Wealden deposits in England (46), the Upper Cretaceous in India (45) and Madagascar (16), the Danian (=uppermost Garumnian) in France (17) and Hungary, and the uppermost Cretaceous or basal Eocene in Argentina (49). The osteology of *Titanosaurus* shows, so far as it has been studied, that this is a comparatively primitive type. The neural spines of the dorsal vertebræ are simple and not bifid. The plate-like structure of the neural arches is not far advanced; nearly all vertebræ, however, even most of the caudal vertebræ, are deeply opisthocœlous. Since this latter feature occurs already in the *Titanosaurus* of the Wealden, its occurrence in the *Titanosaurus* of the Upper Cretaceous implies no progress, but a stagnation in evolution. The humerus of *Titanosaurus*, although strongly expanded at both ends, and thus differing from the slender humeri of the Brachiosauridæ (68), is comparatively long; the metapodials are comparatively slender; the scapula shows no strong crista, and differs thus from the more highly specialized scapula of *Diplodocus* (31). Altogether, *Titanosaurus* is a type which, despite its opisthocœlous caudal vertebræ, shows no such marked specialization as the Brachiosauridæ or Diplodocidæ.

Seeing that, up to the present day, scarcely anything is known of the trend of evolution in the phyla of Sauropoda, it is not easy to fix the phylogenetic value of the last of the Sauropoda; but even the characters described in the foregoing paragraph show that it is not an aberrant terminal of some highly-developed phylum. Together with *Kallokibotion*, *Rhabdodon*, *Orthomerus*, and *Struthiosaurus* also, the Wealden genus *Titanosaurus* seems in the Cretaceous to be out of date.

III. Comparison of the Fauna with others.

The occurrence of a primitive tortoise, a primitive Camptosaurian, a primitive Protrachodont, a primitive Sauropod, and a not very specialized Acanthopholid Dinosaur in the Upper Jurassic or Lower Cretaceous of Europe, would in no way be remarkable. But, if we consider that all the types enumerated above are forerunners of more highly-specialized types during the Cretaceous Period, and if we recollect that they occur all together at its end, the matter bears another aspect. We are not dealing in this case with a few survivals, such as might be dismissed under the

convenient appellation 'sporadic,' but with the survival of a primitive fauna. At this point, it becomes obvious why it was important to fix the age of this fauna beyond all doubt.

In recent times a situation similar to that established for Transylvania in the Cretaceous Period is only to be met with in Australia, where the diluvial and prehistoric fauna likewise consisted exclusively of elements that had long vanished in other parts of the globe.

Having established this fact, we must try to find the reason. Practically the same fauna as in the latest Cretaceous of Transylvania is met with in the Garumnian of Southern France, where, among others, *Rhabdodon priscum* occurs, as well as a *Hierosaurus*-like plated Dinosaur (18) which evidently is closely allied to *Struthiosaurus*, the same crocodile as in Transylvania. But the tortoises are different, the French *Polysternum* (67) probably being merely a pathologically deformed member of the Amphichelydæ. The French Sauropod *Hypselosaurus* (50) seems to be closely allied to *Titanosaurus*, although generically distinct, and *Titanosaurus* itself occurs at St. Chinian (17). From the Maestrichtian strata in Belgium are known the Dinosaurs *Orthomerus* (19, 72) and a form allied to *Iguanodon*, called *Craspedodon* (19), as well as a Theropodous Dinosaur of uncertain systematic position denominated '*Megalosaurus*' *bredai* (72). The crocodile *Thoracosaurus* (38) differs from the Danian type. Other land-animals are not known in the Maestrichtian.

From the Turonian strata of Lower Austria come *Rhabdodon* (73) represented only by fragments of an immature male; *Struthiosaurus*, male and female; and a short-snouted crocodile *Rhadinosaurus* (13), traces of which have been found in Transylvania and France. The tortoises are too badly preserved to permit identification; the Pterosaurian seems to belong to the Ornithocheiridæ, but this is not quite certain. Going back from the Turonian to the Cambridge Greensand, we find numerous Ornithocheiridæ, a *Rhabdodon*-like animal *(Anoplosaurus)*, then a Trachodont Dinosaur related probably to the Protrachodontidæ (48). Moreover, there occurs a species of *Acanthopholis* (71, 54) and a large Sauropodous Dinosaur, *Macrurosaurus* (71).[1] Crocodiles of uncertain systematic position [*Crocodilus proavus* Seeley, etc. (69, 70)] occur likewise.

The farther we go back in the chronology, the more types are to be met with differing from the Transylvanian fauna. Even if we admit that the differences are to a certain extent due to zoo-geographical distribution, this does not explain every circumstance, *Rhabdodon* and *Orthomerus* having co-existed in England with *Macrurosaurus*, and in Belgium with *Craspedodon*. Therefore the Transylvanian fauna, well known in consequence of the vast amount of collecting that has been in progress for twenty-five

[1] A revision of the Dinosaurs of the Cambridge Greensand will be published elsewhere.

years, turns out to be in reality nothing else than the poor remains of an older and richer but less-known fauna.

Thus we have not only to deal with a primitive fauna, but with one in which the genera are reduced in numbers while individuals are abundant. Apart from this, the small size of the Dinosaurs should be noted, the biggest not exceeding 18 feet in length, tail included.

IV. Palæogeographical Data.

Leaving now the palæontological aspect of the question and reverting to the geological aspect, we find by consulting the most accurate palæogeographical maps of the Cretaceous Period, such as A. de Lapparent's (41) or E. Haug's maps (29), or those of T. Arldth (3), that the southern part of present day Europe, which had been a great mass of dry land during Neocomian times, had become during the Cenomanian a mere archipelago. Apart from the island which comprised the western part of Great Britain, Normandy, and Western Spain, and a second island in the centre of Germany, one island covered the South of France, Corsica, and Sardinia, another island or part of one embraced the Alps, Hungary, Serbia, Macedonia, and Thrace, and still another the Dobrudsha and a great part of Southern Russia. From the great continent that lay in the north, and extended eastwards towards Asia, these islands were separated by a continuous channel running from west to east. Until Lower Senonian times the distribution of land and water seems to have remained practically the same. Between the Lower and Upper Senonian occurred, as I succeeded in establishing in co-operation with Prof. Murgoci, that great tectonic movement which produced the present Carpathian ranges, and therewith the main outlines of recent European topography. This movement was evidently followed by a period of local emergence; but, not long afterwards, the emerged regions were partly invaded once more by the sea. Perhaps the invasion occurred in the rear of the overthrust masses, while the overthrust was going on.

The Upper Senonian sea did not in Eastern Hungary invade that great tract of land which had been covered by its predecessor, but the newly-formed depressions; thus, in accordance with the new topography, it was more or less restricted to the depressions still existing. Two small islands were left uncovered, one corresponded in some way to the actual mountains of Bihar, another in a vague manner to the Transylvanian Alps. These were the small areas to which the Dinosaurs were restricted during Upper Senonian time.

As the brackish-water beds of Alvincz show, the land soon began to emerge again, and the areal range of the Dinosaur extended; finally, the isolated tracts united and formed again a large mass of dry land, with freshwater lakes and great freshwater swamps between them. These lakes lay where during the overthrust, behind the overthrust sheets, depressions had been formed. While

the whole continent rose, these depressions continued to become deeper. This sinking caused the local accumulation of 6000 feet of coarse gravel and even conglomerate, showing no decrease in the size of its constituents, and proving thus that the gradient of the fall of the different rivers entering into the lake was for a very long time the same.

For the information of those unacquainted with such gigantic non-marine accumulations, it is worthy of note that, at a later period in the Carpathians, the brackish-water transition-beds between the Oligocene and the Miocene (the Aquitanian strata), which likewise consist of clays, sandstones, conglomerates, and layers of coal, attain near Petrozseny a thickness exceeding 2100 feet (53).

It is similarly interesting to note, as a second example of the sinking of the base while sedimentation is going on, that in the great Hungarian plain (Alföld) the diluvial–fluvial accumulations go down at Zombor to a depth of 62 feet, at Szabadka to 290 feet, and at Szeged to 386 feet. Nevertheless, the grain of the sediment does not change in the least, and it continues to be the same even in the Levantic strata, which go down at Zombor to 300 feet below the uppermost diluvial sediments, and in Szabadka to 800 feet. The Pontic strata were nowhere encountered, although one of the artesian wells which furnished the data was driven at Szabadka to 1800 feet (27).

Evidently, similar processes account for the 6000 feet of Danian rocks at Hátszeg, which continued to transgress continuously over older strata, although the surface of the country as such was rising.

The maximum of emergence was attained in Southern Europe at the dawn of the Eocene, when even the Danian lakes and swamps were drained by rivers, and it seems as if at that time the different patches of dry land in South-Eastern Europe were united to the Russo-Asiatic continent. Evidently, the newly-formed land-bridge brought the Eocene mammals into Europe. In the Middle Eocene sediments of Transylvania *Prohyracodon orientalis* and *Brachydiastematherium transylvanicum* are already to be met with (37). The Lower Eocene is missing in the whole of Transylvania (36).

V. The Causes of the Extinction of the Upper Cretaceous Vertebrates.

Taking into account the geological changes set forth in the foregoing pages, we can easily understand why ancient pre-Cenomanian types of terrestrial animals persisted in South-Eastern Europe until the end of the Danian stage. We can, moreover, find an explanation for the remarkably small size of the Dinosaurs of this fauna, for that seems to be an effect of the restriction to the small Senonian islands, which affected neither the smaller crocodiles nor the comparatively small tortoises, but only the

bigger creatures. This dwarfing is very similar to that observable as dating from Pliocene times on various Mediterranean islands, where only the comparatively large mammals decrease in size, while the originally rather small tortoises and originally small mammals retain their normal size, or seem even to become bigger.[1] Insular isolation, therefore, seems to act differently according to the size of the animals that are isolated. Apart from all this, we can discern some of the various reasons that led to the extermination of this fauna. One factor was assuredly the invasion of Asiatic mammals, which probably disturbed the helpless Dinosaurs of the *terra firma*, such as *Struthiosaurus* and *Megalosaurus*, in much the same manner as the recent placental mammals of Australia disturb the Marsupials of that country. The possibility of such an invasion becomes quite evident if one studies Karpinsky's maps, reproduced in Dacqué's book (14).

Another factor which probably led to the extermination of the herbivorous Dinosaurs inhabiting the lakes and swamps was the drying-up of the country, and lack of marsh-vegetation.

The flora of the Danian and Senonian rocks of South-Eastern Europe is different from the Eocene flora. In Danian times the forests of Eastern Europe consisted, as shown by the works of L. de Launay (15), Zeiller (79), Staub (75), and Tuzson (76), of *Cunninghamites*, *Damarites*, *Ternströmia*, *Credneria*, *Sassafras*, *Ficus*, Tree-Ferns, and Araliaceæ: in their shade grew ferns, such as *Asplenium*, *Gleichenia*, and *Pecopteris*. In the forest-glades lofty palms arose, such as *Sabal* and *Jurania*; while on the marshy grounds near the lakes, *Pandanites* trees grew on a ground covered with *Arundo*. All this indicates a moist and warm climate. In contrast to this, the Hungarian Lower Eocene contains already great numbers of walnut-trees (77), and therefore trees that regularly shed their leaves. This shows, that on the Eocene continent, perhaps because of lack of moisture, the temperature had sunk lower.

It is a well-known fact that the higher Dicotyledonous flora appears in the Cretaceous Period, and thus it seems that the change in the flora precedes the change in the animals that feed upon it. Curious as this may appear, there is a parallel in earlier ages, for at the end of the Palæozoic Era the appearance of the *Glossopteris* flora in the Southern Hemisphere and its spread northwards precede in a similar manner the extinction of the herbivorous Palæozoic reptiles *Pareiasaurus*, Dicynodonts, and Dinocephalia.[2]

The explanation is quite simple, for the flora is directly affected by every change of climate; while the animals for the greater part

[1] D. M. A. Bate, 'On a small Collection of Vertebrate Remains from the Har Dalam Cavern, Malta, &c.' Proc. Zool. Soc. 1916, p. 421; 'On Remains of a Gigantic Land Tortoise from the Pleistocene of Menorca' Geol. Mag. 1914, p. 100; 'Preliminary Note on the discovery of a Pigmy Elephant in the Pleistocene of Cyprus' Proc. Roy. Soc. vol. lxxi (1903) p. 498; and 'Further Note on the Remains of *Elephas cypriotes* from a Cave-Deposit in Cyprus' Phil. Trans. Roy. Soc. ser. B, vol. cxcvii (1905) p. 347.

[2] See fig. 325, p. 430, in Potonié's 'Lehrbuch der Paläobotanik' 2nd ed. by Gothan, Berlin, 1922.

feel it indirectly, so long as the change is not very violent or abrupt. Thus, even those feeding on a certain flora may linger on for a while after its extinction.

As to the Ornithocheiridæ, it was, I believe, not so much the rivalry of the birds that led to their extinction (for birds and Pterosauria occur together from Jurassic times onwards), but the change in climate. The Pterosaurians are the only reptiles (for reptiles we must call them) in which we have to presume, despite Arthaber's arguments (5), that the body-temperature was high, although they had no heat-preserving integument.

Already in the Crocodilia (which belong to the Archæosauria, and therefore are closely allied to the Pterosauria) the separation of the heart-chambers indicates a comparatively advanced stage (12, 26). They present, besides, several structures that prevent as long as possible an influx of blood poor in oxygen into the brain (12); this shows how sensitive is the brain in that respect.

In Pterosaurians the brain is much more developed than in crocodiles; besides, it shows a marked increase of size in the course of evolution, being larger in the Ornithocheiridæ than in *Parapsicephalus* (4), and we may quite safely infer that in these animals it was at least as sensitive to carbon dioxide as in crocodiles. This supports the argument, as H. G. Seeley pointed out, for a heart with separated chambers, whereby the body-temperature would be raised. Where in human pathological cases the heart-chambers communicate, the body-temperature attains only 32° C. (77).

Not only the circulatory, but also the respiratory, organs of Pterosaurians indicate that the body-temperature was comparatively high. In these agile reptiles the air-sacs were not developed according to the usual reptilian type, but extended even into the bones. In birds the air-sacs serve, as proved again by Bær (6), to augment in every possible manner the contact of fresh air with the rapidly circulating blood. In the lightly-built primitive Dinosaurs (62) and Pterosaurians their function was probably the same. In lizards the heart beats 10 to 200 times, in birds 300 to 1000 times, in a minute. This second argument corroborates, so far as Pterosaurians are concerned, the conclusions arrived at by means of the first. As for Dinosaurs, I do not believe that they were warm-blooded, for, in the course of their evolution, the brain degenerates (62).

While all mammals and the warm-blooded birds have a heat-preserving integument, the Pterosauria had none. They must, therefore, with a falling temperature have suffered more from cold than mammals or birds; and, since the change of the flora at the end of the Cretaceous Period indicates a cooling of the climate, perhaps we may have here a clue to their disappearance (25, 35).

The coincidence of the extinction of Pterosauria in America with the appearance of the Kainozoic flora (11) is a most extraordinary feature, for no direct connexion seems to exist between fish-eating Pteranodontidæ and plants. This indicates the direct influence of the climate.

The only groups of reptiles that survived in South-Eastern Europe beyond the end of the Cretaceous Period were the tortoises, which had managed to live on ever since Triassic times, and the true Crocodilia. Even among the tortoises, a diminution is to be found, for the old genera are in part replaced by new ones which appear to have come from Asia. In the Crocodilia, however, it seems as if the new Kainozoic forms were the descendants of the older forms.

Since the Mesosuchia retreated, as Prof. L. Dollo remarked, at the end of the Cretaceous Period into warmer regions, where they managed to live on into the Eocene (20), the survival of Eusuchia seems at first all the more curious. The reasons for this difference were, however, already in part demonstrated many years ago by Thomas Huxley (34). It is obvious that, for crocodiles who had fed during the Mesozoic Era on sluggish reptiles which could only be torn to pieces or swallowed half alive, in Tertiary times (when they were rather suddenly compelled to live almost exclusively on birds and agile mammals) the drowning of the prey became of very great importance.

There are three reasons why the Eusuchia were not likewise exterminated at the end of the Cretaceous Period, as were the Dinosaurs and the other Reptilia. First of all, these animals, although living in water, were independent of its vegetation, and did not suffer from the draining of the swamps; they were, therefore, better off than the Sauropoda and the Ornithopodidæ. Secondly, the different nature of their hunting-grounds prevented them from coming into collision with the Eocene terrestrial carnivora, as did the Theropoda. Lastly, they suffered less from the change of climate than the Pterosauria; for, on account of their low body-temperature, they did not feel the loss of heat. It was only at the end of Miocene time, when the European climate became much colder, that the crocodiles were expelled from Europe together with the palm-trees and the remainder of the subtropical vegetation, and driven towards the tropics.

To sum up, we see how the preservation of a primitive Jurassic land-fauna until the end of the Cretaceous Period was brought about by a geographical factor, and then we see again how the alteration of this factor led, in part directly, in part indirectly, to the nearly total extermination of that fauna.

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DISCUSSION.

Dr. A. SMITH WOODWARD welcomed this paper as another contribution to our knowledge of the Cretaceous Dinosaurs, which had often been discussed by the Society. He had visited Transylvania with the Author, and was able to confirm several of his interesting geological observations. He thought the Author's interpretation of the Dinosaurian fauna in question, as representing the life of an island, both ingenious and satisfactory. He was glad to add that the most important part of the Author's collection was already in the British Museum, and he hoped that the remainder would follow.

Prof. W. W. WATTS was much interested to learn that sedentary and armoured Dinosaurs had exceptionally small brains. The geological record seemed to show that 'passive resisters' relying upon armour, horns, etc. were always worsted in competition with those developing teeth, claws, and speed. The still more active flying creatures would naturally require better brains, and he asked the Author if it were possible to indicate whether the development of wings had preceded or followed the brain-development.

The CHAIRMAN (Mr. R. D. OLDHAM) remarked on the interest of the paper, as illustrating the Lyellian principle of continuity between the past and the present, by the evidence which had been produced of the existence in Cretaceous times of conditions very similar to the present-day survival of an atavistic fauna in the Australian islands.

The AUTHOR, replying to Prof. Watts's question, said that he believed the development of brain and power of flight to be reciprocal, and so it was not possible to aver that one gave rise to the other. While agreeing completely with Prof. Watts that the development of armour was likely to affect the quality of the brain, he nevertheless pointed out that the reduction of brain is remarkable in all Dinosaurs, and not only in the armoured forms.

In answer to the Chairman's remark, the Author stated that, in the paper itself, he had not omitted to draw attention to the recent Marsupial fauna of Australia.

[April 11th, 1923.]

5. *The* Geological History *of the* Genus *Stratiotes*: *an* Account *of the* Evolutionary Changes *which have occurred within the* Genus *during* Tertiary *and* Quaternary Times. By Miss Marjorie Elizabeth Jane Chandler. (Communicated by Mrs. E. M. Reid, B.Sc., F.L.S., F.G.S. Read April 12th, 1922.)

[Plates V & VI.]

I. Introduction.

Stratiotes aloides, the Water-Soldier or Water-Aloe, is a well-known monotypic European and Siberian plant of the Monocotyledonous family Hydrocharitaceæ; palæontological studies of recent years have shown this plant to be the sole survivor of an ancient genus which was living far back in the Tertiary Era.

II. History of Palæobotanical Investigation.

The principal land-marks in the palæobotanical study of *Stratiotes* are as follows:—

1, 1822. The description of *Carpolithes thalictroides* Adolphe Brongniart; var. *parisiensis* (Paris Basin); var. *websteri* (Newport, Isle of Wight) (2).[1]

2, 1833. Description of a second species, *Folliculites kaltennordheimensis* Zenker, and the suggestion that Brongniart's fossils belonged to this genus (7).

3, 1892. Description of a third species, *Paradoxocarpus carinatus* Nehring, from Pleistocene beds (33).

4, 1892, later. Recognition that Nehring's *Paradoxocarpus* was a species of *Folliculites* of Zenker, by Potonié (36).

5, 1896. Identification of *Folliculites* as *Stratiotes* by Keilhack (54, 56), *F. carinatus* being synonymous with *S. aloides* Linn. and *F. kaltennordheimensis* being an extinct species.

Apart from these points, the whole literature of the subject is a mass of controversy. The confusion has been increased by the fact that *S. websteri* and *F. kaltennordheimensis* had been inadequately figured and described; while, owing presumably to a strong generic resemblance, shown by the figures (which failed, nevertheless, to make clear the specific distinctness), the two names were frequently used as synonyms. The disorder occasioned could not be cleared up by an appeal to type-specimens, for, in the case of *Stratiotes websteri*, these, and the type-locality too, were lost. Moreover, other species had also become involved in the chaos under one or both of the two names.

[1] Numbers in parentheses refer to the Bibliography, § IX, p. 133.

In order to illustrate the difficulty thus occasioned, the following instance is given. In the Isle of Wight four different species occur at three different horizons, namely: *S. headonensis*, sp. nov., in the Lower Headon Beds; *S. neglectus*, sp. nov., in the Bembridge Series; *S. acuticostatus*, sp. nov., and another which has been retained as *S. websteri* (see below) in the Hamstead Beds. All these four had, at one time or another, been referred to *S. websteri*, which had thus become a group-name to indicate any *Stratiotes* from the Isle of Wight. But the absence of the types, and ignorance as to which of the green clays near Newport had yielded those types, combined with the poorness of the figures and descriptions, left as a matter of doubt which of the four species was the original *S. websteri* of Brongniart. Clearly, therefore, it was necessary to go back to the beginning, and to obtain types (where possible) which could be carefully compared. These have been obtained in every instance but that of *S. websteri*. But in 1901 Zinndorf (60) had described and figured carefully under this name a *Stratiotes* from the Upper Middle Oligocene of the Mayence Basin, and his species agreed in all respects with one of the English forms from the Hamstead Beds. In order to keep an old name, familiar in the past literature of the subject, this species of Zinndorf has been retained as *S. websteri* Zinndorf (? Brongniart).

III. *Stratiotes aloides*: Diagnosis of Fruit and Seed.

In order that the relationship of the fossils with *S. aloides* may be appreciated, and the past changes in the genus understood, a description is given of the living seed.

Fruit.—Excellent accounts of the fruit are extant by Lubbock (39) and Nehring (57); but, as the seed alone is preserved in fossilization, the structure of the fruit is of no consequence here.

Seed.—From one to four occur in each locule, generally a few are abortive and stunted. Each seed is anatropous, almost erect, situated in the locule with its raphe towards the centre of the fruit, while the nearly contiguous hilum and micropyle are directed towards the outside wall. In shape bisymmetric, oblong, narrow and bolster-like, slightly hooked at the base, and very slightly flattened laterally; provided with a keel in the plane of symmetry running down one side from the apex to the base, and continued just round the base on to the opposite side; the keel carries the raphe. At the proximal end a small knob-like projection, the 'collar', occurs; it is penetrated by the micropyle, and its presence determines the hooked form of the seed. The collar is separated from the main body by an ill-defined constriction—the 'neck'. (See text-figure 1, p. 119 & Pl. V, fig. 23.)

The testa consists of three layers: (i) An outer layer of spirally thickened cells, which swell in water and become mucilaginous. This is generally destroyed wholly or in part during

fossilization, but traces of it may frequently be seen clinging to the surface of the fossils. (ii) A thin woody layer ornamented externally by a series of pits arranged more or less regularly in longitudinal rows. (iii) A thin, closely adherent skin lining the seed-cavity, which consists of elongate spirally-thickened cells with double walls crossed by fine canals (see Pl. VI, fig. 22). The woody layer (i), as a rule, forms the surface in the fossils; the thin inner skin (iii) is frequently well-preserved, and in all species it shows the same microscopic features.

Fig. 1.

Fig. 2.

The proximal end of the seed with its collar is defined as the base, and the opposite end as the apex; the keeled edge is the dorsal, and the opposite edge the ventral side.

In germination the testa splits into symmetrical halves from the base along the keel to the apex, and, although these halves may remain joined for a time, they eventually fall apart.

The interior of the seed shows the basiventral micropyle, passing through the wall either very obliquely, horizontally, or in a reflexed manner, and narrowing markedly towards the exterior; it also shows the raphe traversing the length of the keeled dorsal margin diagonally, and entering the cavity at the apical chalaza (see text-figure 2, above, and Pl. VI, fig. 20).

The tegmen is thin, and is attached at the base to the testa by a thread which passes into the micropyle; at its apex a black hat-shaped structure (the 'caruncula' or 'hütchen' of German writers) marks its attachment to the chalaza (fig. 2, p. 119). The cells of the tegmen are elongate, with beaded walls (Pl. VI, fig. 21). In recent seeds the embryo lies within the tegmen; but, as it is absent in the fossils, where the seed-cavity is occupied by the empty tegmen only, it does not concern us here.

The length of fully developed recent seeds is from 9 to 7·25 mm., and the breadth about 2·5 mm.

IV. The Fossil Species.

The fossil seeds all conform to the general structure described above, although they show modifications in detail, giving rise to a graded series of species so closely linked that, in the absence of all parts of the plant but the seeds, it is illogical to separate any one species as a distinct genus. Attention is drawn to this point, because attempts have been made among German palæobotanists to retain the Tertiary species as *Folliculites* (44, 60, 70, 72, 73).

As the result of recent investigations, nine species are recognized:—

9. *Stratiotes aloides* Linn.: Pleistocene and Preglacial.
8. *S. intermedius* Hartz: Preglacial.
7. *S. tuberculatus* E. M. Reid: Lower Pliocene and Upper Miocene.
6. *S. kaltennordheimensis* Zenker: Lower Miocene.
5. *S. thalictroides* Brongniart: Upper Oligocene.
4. *S. acuticostatus*, sp. nov.: Hamstead Beds, Middle Oligocene.
3. *S. websteri* Zinndorf (? Brongniart): Hamstead Beds, Middle Oligocene.
2. *S. neglectus*, sp. nov.: Bembridge Beds, Middle Oligocene.
1. *S. headonensis*, sp. nov.: Lower Headon Beds, Upper Eocene.

Thus a series is known stretching far back into the Tertiary, some forms being close in time, others separated by gaps which further search may ultimately help to fill.

V. Evolutionary Changes, and the Relationship between the Different Species.

In studying evolutionary changes, it is logical to pursue them in the order in which they have taken place in Nature; therefore, the changes in the genus will be followed from the oldest to the newest species.

The form of the seed.—Eocene seeds are small, short, and broad; Oligocene, Miocene, and early Pliocene seeds are (on the whole) sturdier and longer; Preglacial, Pleistocene, and recent seeds are long and narrow (see Pl. V, figs. 1 to 23).

The collar and neck.—In Eocene, Oligocene, and Miocene species the neck is well-defined, hence the collar is conspicuous; Preglacial, Pleistocene, and recent examples have an ill-defined

neck and small collar; consequently, body and collar are less clearly distinguished one from the other, and the hooked form of the seed, due to the lateral projection of the collar, is less marked (see Pl. V, figs. 1 to 23).

The keel has passed through three stages: (*a*) in the Eocene species it stops short of the base on the dorsal side, does not merge into the collar, but terminates against the neck or the top of the collar (Pl. V, figs. 1 & 2). (*b*) In Oligocene and Lower Miocene species it still ends on the dorsal side, but extends to the base of it, and gradually merges into the collar (Pl. V, figs. 4 to 6, 7, 10 to 15). (*c*) In Upper Miocene to recent species it is continued round the base of the seed, below the collar, and terminates on the ventral side (Pl. V, figs. 16 to 23).

The testa.—In older forms the testa is thick and woody, the external ornamentation rugged and pronounced. In the Eocene species especially, but also in some Oligocene species, the longitudinal rows of tubercles of the external surface are so arranged as to give a ribbed appearance to the seeds (Pl. V, figs. 1 to 12). In Miocene and Pliocene species the elongate tubercles still tend to be arranged in longitudinal rows, and are still abundant (Pl. V, figs. 15 to 17). In the Preglacial *Stratiotes intermedius*, tubercles are very distinct, but sparsely scattered (Pl. V, figs. 18 & 19). In Pleistocene *S. aloides*, tubercles may or may not be present (Pl. V, figs. 20 to 22): if present, they are ill-defined and few. In recent *S. aloides*, tubercles are absent; but occasionally the surface is obscurely angulate (Pl. V, fig. 23).

The micropyle.—In Headon and Bembridge seeds, basal or sub-basal, only slightly oblique (Pl. V, figs. 24–28); in the Hamstead species, *S. acuticostatus*, sub-basal and oblique (Pl. V, figs. 29 & 30); in Lower Miocene seeds, sub-basal and very oblique (Pl. VI, figs. 9–11); in Upper Miocene to recent species basiventral and very oblique, horizontal or even recurved (Pl. VI, figs. 12–15, & 17–20).

The raphe.—In Upper Eocene species, usually marginal from base to apex, passing directly to the seed-cavity (Pl. V, figs. 25 & 26) at the apex; in Middle Oligocene species, marginal from the base to the middle of the dorsal side, thence diagonal to the apex, the diagonal portion being therefore abrupt and short. Two minor modifications occur in the Oligocene; in *S. neglectus* (Bembridge) the diagonal part is curved, and divides the dorsal wall either equally, or so that the part external to the diagonal is rather narrower than the part internal to it; in the closely allied *S. acuticostatus* (Hamstead) the diagonal part of the raphe is less curved, and so divides the dorsal wall that the width of wall outside is equal to, or more commonly greater than, the width inside (see Pl. V, figs. 27 & 28 with figs. 29 & 30).

In Lower Miocene to recent species the raphe runs diagonally from the basal hilum to the apical chalaza. *S. kaltennordheimensis* shows the first occurrence of this long diagonal type (Pl. VI,

figs. 9–11). A slight modification of it is seen in *Stratiotes tuberculatus*, where the raphe enters the seed-cavity slightly below the apex, in such wise that the diagonal is a little shorter and more abrupt than in *S. kaltennordheimensis* and *S. aloides* (Pl. VI, figs. 12–14, 16).

The cells of the interior of the keel.—In Headon and Bembridge species these are very complex; interlocking digitations are developed across the keel from seed-cavity to external edge. The digitate cells are convolute, contorted or puckered, so that complicated patterns are produced (Pl. VI, figs. 23 & 24). In Oligocene and Lower Miocene seeds, the digitate cells are elongate parallel to the long axis of the seed, and may still be traced across the width of the keel (Pl. VI, figs. 25–27). *S. tuberculatus* (Upper Miocene, Lower Pliocene) is interesting, for, while it retains the sturdiness and the rugose ornamented testa of the older species, in the cell-structure of its keel it forms an important link between these older species (which some would still place in the genus *Folliculites*) and the Pleistocene and recent species. Thus the digitate cells are found at the inner edge of the keel; but they give place to non-digitate, elongate, parallel-sided cells on the keel itself, a character which is also seen in *S. intermedius* and *S. aloides* (Pl. VI, figs. 28–31). In keel and micropyle *S. tuberculatus* also approaches these more recent forms (p. 121), yet the fact of its belonging to the same genus as *S. kaltennordheimensis* cannot reasonably be questioned (see Pl. V, figs. 15–17 and Pl. VI, figs. 9–14).

The Pleistocene and Preglacial *S. aloides* furnishes a complete evolutionary series, in which gradual changes can be traced from faintly tuberculate individuals that recall *S. intermedia* to perfectly smooth examples indistinguishable from the type (recent) *S. aloides*. These tuberculate and smooth forms are found side by side in the same bed, which may furnish a graded series of specimens illustrative of the passage from one to the other. The evolutionary series is so completely set forth that it is impossible to draw a dividing-line between those provided with tubercles and those (like the recent *S. aloides*) lacking tubercles. An earlier stage is probably represented by the closely-allied *S. intermedius*, in which the rugosity of the testa is a constant character, and it is the occurrence on the one hand of this rugose Preglacial fossil, and on the other of a recent smooth seed, which brings out the significance of the association of smoother and rougher individuals in Pleistocene deposits (see Pl. V, figs. 18–23).

Thus the Tertiary and Quaternary Eras furnish a connected series, the members of which constitute links in an evolutionary chain, while sufficient evidence remains to indicate something of the general lines along which changes have taken place.

VI. A Subsidiary Evolutionary Series.

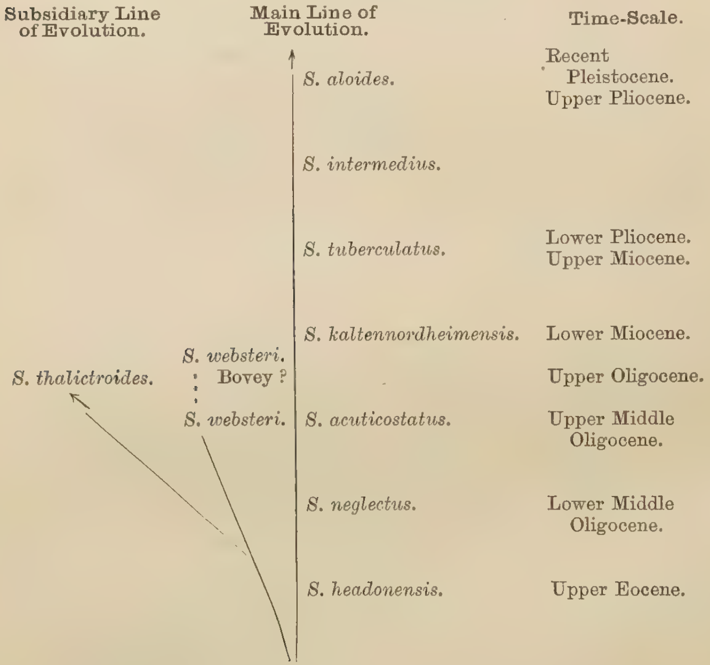
The species just discussed perhaps illustrate the main trend of evolution in the genus *Stratiotes*; but, in addition, a branch-line, which has left no descendants, is represented by two species in the Oligocene: *S. websteri* Zinndorf (Middle Oligocene) and *S. thalictroides* Brongniart (Upper Oligocene). *S. websteri* is peculiar in having a hilum which varies in position from the middle of the dorsal margin to the apex: when apical it is almost always associated with a beak, and this gives rise to a sigmoidal seed; for other positions of the hilum the beak is absent or feebly developed, its absence giving rise to the common hooked form of seed. The canal of the raphe is also remarkable: when the hilum is mid-dorsal, it is marginal to the apex and then transverse; for other positions of the hilum it is transverse, either obliquely or directly. It occurs in widespread localities—in the Bovey Tracey lignite of Devon, the Hamstead Beds of the Isle of Wight, and the Middle Oligocene *Cyrena* Marls of the Mayence Basin (Pl. V, figs. 7–12, 31 & Pl. VI, figs. 1–5).

S. thalictroides in the Upper Oligocene of the Paris Basin is known only from casts, but it shares the same peculiarities of form and structure. It is more elongate than *S. websteri*, the average relation of length to breadth in *S. websteri* being only 2·315 and in *S. thalictroides* 3·5, while in individuals of this species it rises to 4 (Pl. V, figs. 13–14 & Pl. VI, figs. 6–8).

The contrast between the short transverse raphe and dorsal hilum of *S. websteri*, and the long raphe and basal hilum of *S. aloides*, etc. led some investigators to separate the two types generically. On these grounds, Zinndorf gave to *S. websteri* the new generic name *Stratiotites* (60). As all other characters of the seed agree with *Stratiotes*, such a separation seems unnecessary, especially as a simple explanation of the short raphe can be suggested. This depends on the fact that in fossilization the outer layer of the testa—a conspicuous feature of *S. aloides*—is nearly always destroyed (see p. 118). In *S. headonensis*, the earliest-known form, the raphe lies on the extreme margin of the woody layer of the testa, but sufficiently within to be preserved. In the succession of species which lead from *S. headonensis* to *S. aloides*, the raphe becomes more and more deeply sunk within the woody layer (see pp. 121 & 122). If, now, it had happened that in the offshoot represented by *S. websteri* the raphe, instead of passing towards the interior, had moved even slightly to the exterior, so as to lie between the median hard and the outer spongy layers of the testa, then, in the process of fossilization, the spongy layer and accompanying raphe would be lost, and the apical part of the raphe (which in its passage to the seed-cavity traverses the median layer) would alone be preserved, resulting in the form seen in *S. websteri*.

VII. Summary and General Conclusions.

The relationship postulated between the different species of *Stratiotes* may be summarized in the following diagram, which is merely a suggestive phylogeny, and is not intended to illustrate the precise limits in time of any of the species :—



Researches on *Stratiotes* have a botanical as well as a geological significance. From the botanical point of view, it is interesting to trace the varied history of a genus which is monotypic at the present time. In regard to the geological value, it is hoped that *Stratiotes* may eventually prove to be a useful time-index in correlating isolated freshwater deposits, for the following reasons :—

(1) We know that some species had a fairly wide geographical range: for instance, *S. websteri* and *S. kaltennordheimensis* (pp. 128 & 130).

(2) There is also good reason for supposing that each species had a limited range in time: thus, in beds so near one to the other as the Bembridge and Hamstead Series, there are distinct, though closely related, forms.

(3) Finally, where *Stratiotes* occurs, it is abundant and readily recognized.

There is one particular case in which it seems possible that this plant may prove of use in correlation. *S. websteri* is known from the Hamstead Beds and the *Cyrena* Marls of the Mayence Basin, both of which are Middle Oligocene. It also occurs in the Bovey

Tracey lignite, which may possibly therefore be rather older than has been generally thought.

I have been enabled to do this work by a grant from the Department of Scientific & Industrial Research, which I hold as a Research Student under Mrs. E. M. Reid.

But for the kindness of many persons, both in this country and abroad, who gave or lent specimens of *Stratiotes*, it would have been impossible to conduct an investigation such as this, which involves the study of material from diverse localities. In this connexion I would mention Dr. Knud Jessen (Denmark), M. Gustave F. Dollfus (France), Dr. W. Gothan, Dr. P. Menzel, and Dr. J. Zinndorf (Germany), and Mrs. Reid, Prof. J. E. Marr, and Mr. G. W. Colenutt in this country.

It had long been realized by the late Clement Reid, F.R.S., that the whole question of *Stratiotes* was in great need of re-investigation, and it was his intention to study the subject thoroughly. With this end in view, he had brought together many examples, including a great number of specimens of *S. aloides*, recent and fossil, from English and German localities, *S. kaltennordheimensis* from various localities in Germany, *S. websteri* from the Isle of Wight, and many specimens of *S. headonensis*; also an extensive literature on the subject.

All this material has been placed at my disposal by Mrs. Reid. For this, and for her many other kindnesses, which include most valuable help and criticism, I thank her very warmly. It has been a great privilege to have been entrusted with the carrying out of this work.

VIII. Description of Species.

1. Stratiotes headonensis, sp. nov. (Pl. V, figs. 1–3, 24–26 & Pl. VI, fig. 23.)

1851. *Carpolithes thalictroides* Brongniart (Wright 11).
1856. *C. thalictroides* Brongniart (Forbes 15).
1862. *Folliculites thalictroides* Brongniart (Bristow 21).
1887. *C.* (*F.*) *websteri* Brongniart (Starkie Gardner 29).
1888. *C. thalictroides* Brongniart (Gardner, Keeping & Monckton 30).

Seed oblong, ovate or tending to be trigonal or quadrangular, hooked at the base, flattened; keel usually very broad and flat, frequently from a third to half the breadth of the seed, not continued round the base, not merging gradually into the collar; collar small, pronounced, warty; testa thick, woody, ornamented with longitudinal ridges which are more or less continuous from neck to apex, where they gradually die out; surface of keel usually without ridges; external pitting of surface fairly coarse and uniform on body and keel. Micropyle basal or subbasal, slightly oblique; hilum basilateral, often marked by an angle at the margin; dorsal wall thickest towards the base; raphe marginal

or nearly marginal to the apex, where it passes directly into the seed-cavity; digitate cells of the interior of the keel very contorted.

Dimensions.—Length=6·5 mm.; breadth=4 mm. (largest example). Length=3·25 mm.; breadth=2·25 mm. (smallest example). Length=4·5 mm.; breadth=3·25 to 2·25 mm. (average specimen).

Horizon.—Upper Eocene, Lower Headon Beds.

Localities.—Hordle (Hampshire); Colwell Bay (Isle of Wight). The species is distinguished by its small size, its flatness, its great breadth, largely due to the broad flat keel, its marginal raphe, and its highly contorted cells on the keel. In worn examples the marginal raphe is frequently in part eroded: it then appears to enter halfway up the dorsal edge of the seed. Many of the Colwell Bay specimens appear to have suffered from the attack of a fungus, as they are frequently distorted, and bear irregular warts or spines; often the distorted specimens are marked by spherical brown pustules, near which they tend to crack.

The Hordle specimens were particularly abundant in Beds 10 and 31 of E. B. Tawney & H. Keeping.[1]

2. Stratiotes neglectus, sp. nov. (Pl. V, figs. 4, 27–28 & Pl. VI, fig. 24.)

1856. *Folliculites thalictroides* var. Brongniart (Forbes 15).
1887. *Carpolithes* (*F.*) *websteri* Brongniart (Starkie Gardner 29).
1889. { *C.* (*F.*) *websteri* Brongniart.
? *F. thalictroides* Brongniart (Bristow-Strahan-Reid 31).

Seed oblong or suboval, hooked at the base, flattened; keel moderately broad to narrow, not continued round the base, merging gradually into the collar. Collar large, prominent, rounded, smooth; testa thick, woody, with irregular longitudinal tubercles often coalescing to form longitudinal ridges, not continued on to the collar, frequently present, although less well-defined on the keel; pitting of surface fairly coarse; micropyle basal or sub-basal, slightly oblique; hilum dorsal, near the base; raphe marginal from the hilum to the middle of the dorsal side, thereafter diagonal to the apex, where it enters the seed-cavity. The curvature of the diagonal portion is such that the width of testa external to the raphe is usually less than the width of testa on its inner side; digitate cells of the interior of the keel tortuous and convolute.

Dimensions.—Length=8·5 mm.; breadth=3·5 mm. (largest). Length=5·5 mm.; breadth=2·5 mm. (smallest). Length=7 mm.; breadth=3·5 mm. (average specimen).

Horizon.—Middle Oligocene, Bembridge Marls.

Localities.—Gurnet (Gurnard) Bay, Hamstead, Thorness Bay, and ? Foreland Point (Isle of Wight). The specimens were abundant in clays and marls, and also in solid blocks of pyrites in the marls.

Affinities.—See *S. acuticostatus* (p. 127).

[1] Q. J. G. S. vol. xxxix (1883) p. 566.

3. STRATIOTES ACUTICOSTATUS, sp. nov. (Pl. V, figs. 5–6, 29–30 & Pl. VI, fig. 25.)

1862. { ? *Folliculites parisiensis* Brongniart / ? *F. thalictroides* var. Brongniart } (Bristow 21).
1862. ? *Carpolithes websteri* Brongniart (Heer & Pengelly 22).
1887. ? *F. websteri* Brongniart (Starkie Gardner 29).
1889. { ? *F. thalictroides* / ? *C. websteri* Brongniart } (Bristow-Strahan-Reid 31).

Seed oblong or narrowly oval, very slightly hooked at the base, flattened; keel generally broad, especially in the larger and better-developed specimens, continued as far as, but not round, the base; collar small, irregular, flattened below; testa thick, woody, ornamented with very conspicuous, sharp, longitudinal ridges, the edges whereof are often serrate, surface of keel showing occasional ridges; pitting very coarse; on the whole outer surface the pits have a tendency to be arranged in transverse rows, which are best seen on the keel and ridges. The outline of the seed when viewed from the interior is crested and serrate at the apex and sides; micropyle subbasal, oblique; hilum at the base of the dorsal edge; raphe marginal from the hilum to the middle of the dorsal margin, diagonal thereafter: the curvature of the diagonal portion is so slight that the width of the testa external to the raphe is equal to or greater than the width of testa on its inner side; digitate cells of the interior of the keel straight, with their length parallel to the length of the seed.

Dimensions.—Length=6·75 mm.; breadth=3 mm. (largest). Length=5·5 mm.; breadth=3 mm. (smallest). Occasionally pockets occur which contain only stunted or undeveloped specimens, the length of these varying from 5·5 to 4 mm. and their breadth from 2·5 to 2 mm.

Although the seed was doubtless originally somewhat flattened, a certain amount of flattening is due to subsequent pressure, since different examples show compression in different directions.

Horizon.—Middle Oligocene, Hamstead Beds.

Localities.—Bouldnor Cliff, Yarmouth (Isle of Wight); Hamstead (Isle of Wight).

Affinities.—This species is very closely related to *S. neglectus*, of which it seems to be a somewhat later form. The chief external features in which it differs from that species are the broader keel, the smaller, more irregular, flattened collar, the sharper ribs, and the very coarse pitting. Viewed internally, the apex and sides show a crested serrate outline; while *S. neglectus*, when similarly viewed, shows an unbroken outline. The chief internal distinction is seen in the diagonal portion of the raphe; in *S. neglectus* this is more curved than in *S. acuticostatus*, with the result that the part of the keel external to the raphe is usually narrower than the part inside the raphe in *S. neglectus*, while it is generally wider than the part inside in *S. acuticostatus*.

4. Stratiotes websteri Zinndorf (? Brongniart). (Pl. V, figs. 7–12, 31 & Pl. VI, figs. 1–5, 26.)

1822. *Carpolithes thalictroides* var. B. *websteri* (Ad. Brongniart 2).
1822. *C. thalictroides* var. B. *websteri* (Ad. Brongniart 3).
1849. *C. websteri* (Ad. Brongniart 9).
1855. *Folliculites minutulus* Bronn (J. D. Hooker 14).
1856. *F. thalictroides* var. Brongniart (Forbes 15).
1862. *C. websteri* Brongniart (Heer & Pengelly 22).
1862. { *? F. parisiensis* Brongniart. / *? F. thalictroides* var. Brongniart (Bristow 21).
1863. *C. websteri* Brongniart (Heer 23).
1874. *C. websteri* Brongniart (Schimper 26).
1887. *C. (F.) websteri* Brongniart (Starkie Gardner 29).
1889. { *F. thalictroides* / *C. websteri* Brongniart } (Bristow-Strahan-Reid 31).
1893. *F. kaltennordheimensis* Zenker (Potonié 48).
1893. *F. websteri* Brongniart (C. Reid in Nehring 44).
1893. *C. thalictroides* var. *websteri* Brongniart (Nehring 44).
1894. *F. websteri* Brongniart pro var. Potonié (Potonié 50).
1897–99. *Stratiotes websteri* (Potonié 58).
1901. *Stratiotites websteri* Brongniart (Zinndorf 60).
1905. *? S. websteri* Potonié (Eugène Dubois 61).
1908. *? S. websteri* Potonié (Engelhardt & Kinkelin 65).
1910. *S. websteri* Brongniart (C. & E. M. Reid 68).
1920. *S. kaltennordheimensis* Zenker (E. M. Reid 71).
1920. { *? F. kaltennordheimensis* var. *minima* / *Stratiotes websteri* / *C. websteri* / *Stratiotites websteri* } (Menzel 72).

Seed oblong, almost cylindrical, but slightly flattened laterally, either somewhat sigmoidal or hooked; keel narrow, often beaked at the apex, frequently convex exteriorly, not continued round the base, merging into the collar gradually; collar large, rounded; testa thick, woody, ornamented with longitudinal ridges which run from neck to apex, where they end in the beak if it be present; pitting rather fine on body, collar, and keel, very fine along the dorsal edge of the keel; dorsal wall broadening greatly towards the apex; micropyle basal or sub-basal, very slightly oblique; hilum dorsal, variable in position: it may occur at any point on the dorsal margin between the middle and the apex, when apical it is almost invariably associated with a beak (sigmoidal seed), otherwise the beak is absent or but feebly developed (hooked seed); raphe short: when associated with a mid-dorsal hilum it is marginal to the apex, and then transverse, for other positions of the hilum the raphe is transverse, either obliquely or directly; digitate cells of the interior of the keel straight, parallel to the length of the keel.

Dimensions.—Length = 7·5 mm.; breadth = 3 mm. (largest). Length = 5·25 mm.; breadth = 2·25 mm. (smallest).

Horizon.—Middle Oligocene (where the horizon is definitely known). ? Upper Oligocene.

Localities.—Upper Middle Oligocene, Süsswasserschicht of the *Cyrena* Marls, Offenbach-am-Main; Hamstead Beds of Hamstead and Bouldnor Cliff, Yarmouth (Isle of Wight); lignite of Bovey Tracey (Devon).

Affinities.—See *Stratiotes thalictroides* (below).

It is interesting to notice that Bristow (21) realized that two species of *Stratiotes* occurred in the Hamstead Beds. In his list of fossils he refers to these as *Folliculites parisiensis* Brongniart and *F. thalictroides* Brongniart respectively. This point has always been overlooked by other workers, who not only failed to discriminate between the two Hamstead species, but also between the Hamstead, Bembridge, and Headon species in the Isle of Wight.

5. Stratiotes thalictroides Brongniart. (Pl. V, figs. 13–14 & Pl. VI, figs. 6–8.)

1822. *Carpolithes thalictroides* var. A. *parisiensis* (Ad. Brongniart 2).
1822. *C. thalictroides* var. A. *parisiensis* (Ad. Brongniart 3).
1833. *Folliculites thalictroides* var. *parisiensis* Brongniart (Zenker 7).
1849. *C. thalictroides* (Ad. Brongniart 9).
1862. *F. thalictroides* Brongniart (Heer & Pengelly 22).
1893. *C. thalictroides* var. *parisiensis* Brongniart (Nehring 44).

Seed oblong, narrow, almost cylindrical, but slightly flattened laterally, sigmoidal; keel narrow, convex exteriorly, with a small beak at the apex, broadening gradually towards the apex, not continued round the base, merging gradually into the collar; collar moderately large, rounded; testa ornamented from neck to apex with longitudinal ridges which terminate in the beak, ridges absent or feebly developed on the keel; pitting coarse, except along the dorsal margin of the keel where it is very fine; micropyle subbasal, slightly oblique; digitate cells obscure.

This species differs in its mode of preservation from all others examined. It occurs as casts, both internal and external, in a siliceous limestone; such casts as were available for study showed the complete external form and sculpture, but (of the interior) only the basal half.

Despite this fact, a comparison of the characters of *S. thalictroides* and of other species lends a high degree of probability to the following inferences :—

(1) The dorsal wall would appear to broaden towards the apex.

(2) The hilum would seem to be associated with the apical beak on the dorsal margin : it certainly cannot have occupied a position below the middle of the dorsal margin, as is seen by studying the available internal casts.

(3) The raphe would seem to be short and transverse, for this form of raphe is associated with the sigmoidal form of *Stratiotes* seed.

Dimensions.—Length = 7·5 to 8 mm.; breadth = 2 to 2·5 mm.

Horizon.—Upper Oligocene, Calcaire de Beauce.

Localities.—Longjumeau, Seine-et-Oise (in the Meulière supérieure, Chattien-Formitien); Villiers, near Pontchartrain; Palaiseau; Villeginis; Chapelle Milon, near Chevreuse.

Affinities.—The distinctive features of the species are its great length and relative narrowness (see p. 123) as also its sigmoidal form. The nearest allied species is *S. websteri*, which occurs at a lower horizon in the Oligocene (see p. 128).

6. STRATIOTES KALTENNORDHEIMENSIS Zenker. (Pl. V, fig. 15 & Pl. VI, figs. 9–11, 27.)

1825. ? *Carpolithes minutulus* (Sternberg 4).
1832. ? *Carpolithes gregarius* (Bronn 6).
1833. *Folliculites kaltennordheimensis* (Zenker 7).
1850. *Nyssa aspera* (Unger 10).
1852–53. *F. kaltennordheimensis* Zenker (Bronn 12).
1855. *Pinus rabdosperma* (Heer 13).
1859. *C. kaltennordheimensis* Zenker (Heer 17).
1859–61. { ? *Hippophae dispersa* / ? *H. striata* } (Ludwig 18).
1861. *F. minutulus* Bronn (Unger 20).
1862. *C. websteri* Brongniart (Heer & Pengelly 22).
1863. *C. websteri* Brongniart (Heer 23).
1874. *Carpites websteri* Brongniart (Schimper 26).
1892. *F. websteri* Brongniart pro var. Potonié (Potonié 36).
1893. *F. kaltennordheimensis* Zenker (Potonié 43).
1893. *F. kaltennordheimensis* Zenker (Nehring 44).
1893. *F. kaltennordheimensis* Zenker (Potonié 48).
1894. *F. websteri* Brongniart pro var. Potonié (Potonié 50).
1895. *F. kaltennordheimensis* Zenker (Nehring 51).
1896. *F. kaltennordheimensis* Zenker (G. Andersson 53).
1896. *S. kaltennordheimensis* Zenker (Keilhack 54).
1896. *S. kaltennordheimensis* Zenker (Keilhack 56).
1896. *S. kaltennordheimensis* Zenker (Nehring 57).
1897–99. *S. websteri* Brongniart (Potonié 58).
1905. ? *S. websteri* Potonié (Eugène Dubois 61).
1908. ? *S. websteri* Potonié (Engelhart & Kinkelin 65).
1909. *S. kaltennordheimensis* Zenker (Hartz 67).
1921. *F. kaltennordheimensis* Zenker (Menzel in Potonié 70).
1920. *S. kaltennordheimensis* Zenker (E. M. Reid 71).
1920. *F. kaltennordheimensis* Zenker (Menzel 72).
1921. *S. kaltennordheimensis* (Kräusel 73).

Seed oblong, occasionally subquadrangular, or subovate, hooked at the base; keel narrow, not continued round the base, merging gradually into the collar; collar large, pronounced, rounded; testa thick, woody, ornamented with elongate tubercles arranged in longitudinal rows, sometimes forming longitudinal ridges; pitting fine, conspicuous over the whole surface; micropyle sub-basal, very oblique; hilum basal; raphe diagonal, passing across the length of the keeled dorsal margin, entering the seed-cavity at its apex; digitate cells of the inner surface of the keel slightly irregular, though approximately parallel to the length of the seed; on those cells that are near the internal cavity the digitations are absent or few.

Dimensions.—Length=7·5 mm.; breadth=3 mm. (largest). Length=5·5 mm.; breadth=2·5 mm. (smallest).

Horizon.—Lower Miocene, Brown Coal.

Localities.—Kaltennordheim (Rhön); Thüringerwald; Salzhausen; Fichtelgebirge; Wetterau (various localities); Mosbach near Wiesbaden, Mayence, etc.; Rav-Pindelag, Copenhagen (remanié).

Affinities.—See *Stratiotes tuberculatus* (p. 131).

A number of very small forms from the Miocene clay of the

Marie ochre-mine, Ringsberg, near Frielendorf (Hessen), have been described by Dr. Menzel as *Folliculites kaltennordheimensis* var. *minima* (72); these he regards as distinct only in their small size from *F. kaltennordheimensis.* I could not examine the specimens; but, judging from the figures, which showed them to have a decidedly sigmoidal outline, I thought it probable that they were small examples of *S. websteri.*

From Dr. Menzel's letters I learnt that *S. kaltennordheimensis* and *S. websteri* had been united under the former name. One would not expect *S. websteri* in Miocene clays, unless it were remanié, and it certainly occurs in the underlying Oligocene of Hessen. This problem can only be solved by the field geologist.

7. Stratiotes tuberculatus E. M. Reid. (Pl. V, figs. 16–17 & Pl. VI, figs. 12–16, 28.)

1920. *S. tuberculatus* (E. M. Reid 71).

Seed rounded-oblong or ovate, hooked at the base, scarcely flattened; keel moderately broad to narrow, convex to the exterior, not merging into, but continued round, the base of the collar as far as the micropyle; collar moderately large, usually conspicuous; testa thick, woody, ornamented with narrow elongate tubercles arranged in longitudinal rows and sometimes forming longitudinal ridges, present also on the keel; pitting fine, conspicuous over the whole surface. The outline, seen from the interior, is often, though not invariably, crested and serrate; micropyle usually basiventral, rarely sub-basal, oblique, horizontal, or seldom recurved, narrowing markedly towards the exterior; hilum basilateral; raphe diagonal, passing across the length of the keeled dorsal margin, entering the seed-cavity below the apex; cells of the inner side of the keel long, narrow, and parallel-sided, not digitate, immediately within the cell-cavity becoming broader, more irregular, and digitate.

Dimensions.—Length=8 mm.; breadth=3·25 mm. (largest). Length=5·5 mm.; breadth=3·25 mm. (smallest). Specimens of average size vary from 7·5 to 6 mm. in length, and from 3·75 to 3 mm. in breadth.

Horizon.—Upper Miocene and Lower Pliocene.

Localities.—Miocene (Pontien) lignite of Chambeuil, Murat (Cantal); Pliocene lignite of Pont-de-Gail, St. Clément (Cantal).

Affinities.—*S. tuberculatus* is very closely related to *S. kaltennordheimensis*; they agree very nearly in the character of the external sculpture, but the form of *S. kaltennordheimensis* is on the whole more slender, and its keel is not continued round the base as in *S. tuberculatus.* Internally, the species may be distinguished by the character of micropyle and raphe: in *S. tuberculatus* the micropyle is commonly horizontal or recurved, while in *S. kaltennordheimensis,* though usually very oblique, it never becomes horizontal or recurved. In *S. tuberculatus* the raphe is diagonal throughout its course and it approaches the seed-cavity very gradually, entering it below the apex of the dorsal side. In

S. kaltennordheimensis the raphe is diagonal, except at its extreme inner end, where it becomes transverse; it enters the seed-cavity at, and not below, the apex of the dorsal side.

The differences just noted are differences of degree rather than of kind, and there can be no doubt that the two species are closely related forms.

On the other hand, in the keel and micropyle, and in the cells of the inner side of the keel, it approaches the Preglacial and Pleistocene species (see p. 122). It thus constitutes a valuable link between the ancient and the modern types of *Stratiotes.*

8. Stratiotes intermedius Hartz. (Pl. V, figs. 18–19 & Pl. VI, figs. 17, 29.)

1906. *S. aloides* Linn. (Menzel 62).
1909. *S. aloides* var. *intermedius* (Hartz 67).
1920. *S. aloides* var. *intermedius* (Menzel 72).

Seed oblong, narrow, feebly hooked at the base, very slightly flattened; keel moderately broad, crested, not merging gradually into the collar, but continued round the base to the micropyle; collar small, insignificant, because not separated from the body by a clearly defined neck; testa thin, woody, ornamented with a few small, but rather acute elongate tubercles arranged in longitudinal rows; pitting fine; micropyle basiventral, transverse or reflexed, narrowing markedly towards the exterior; hilum basal; raphe diagonal, traversing the length of the dorsal and basal walls; cells of the interior of the keel narrow, parallel-sided, not digitate, becoming broader, more irregular, and digitate at the edge of the seed-cavity.

Dimensions.—Length=10 mm.; breadth=3 mm. (longest). Length=9 mm.; breadth=3 mm. (shortest).

Horizon.—Preglacial.

Localities.—Amber-Pin Beds of Copenhagen. These beds are Pleistocene, but they contain an admixture of Tertiary and Quaternary plants. Preglacial Beds of Eime, near Banteln (Hanover).

Affinities.—See *S. aloides* (p. 133).

9. Stratiotes aloides Linn. (fossil forms). (Pl. V, figs. 20–22 & Pl. VI, figs. 18–19, 30.)

1856. ? *Folliculites neuwirthianus* (Massalongo 16).
1878. ? *F. neuwirthianus* Massalongo (Sordelli 28).
1892. ? *F. neuwirthianus* Massalongo (R. von Wettstein 41).
1892. *Paradoxocarpus carinatus* (Nehring 34).
1892. *P. carinatus* (Nehring 35).
1892. *F. carinatus* Nehring (Potonié 36).
1892. *P. carinatus* (Nehring 37).
1893. *F. carinatus* Nehring (Potonié 43).
1893. *P. carinatus* (Nehring 44).
1893. *P. carinatus* Nehring (Weber 45).
1893. *P. carinatus* Nehring (Weber 46).
1893. *P. carinatus* Nehring (Weber 47).
1893. *F. carinatus* (Nehring) Potonié (Potonié 48).

1893. *P. carinatus* Nehring (Clement Reid 49).
1894. *F. carinatus* (Nehring) Potonié (Potonié 50).
1895. *F. carinatus* (Nehring) Potonié (Nehring 51).
1895. *F. carinatus* (Nehring) Potonié (Nehring 52).
1896. *F. carinatus* Nehring (G. Andersson 53).
1896. *Stratiotes aloides* Linn. (Keilhack 54).
1896. *S. aloides* Linn. (Nehring 55).
1896. *S. aloides* Linn. (Keilhack 56).
1896. *S. aloides* Linn. (Nehring 57).
1897–99. *S. aloides* Linn. (Potonié 58).
1899. *S. aloides* Linn. (Clement Reid 59).
1905. ? *S. websteri* Potonié (Eugène Dubois 61).
1906–07. *S. aloides* Linn. (Schröder & Stoller 63).
1907. *S. aloides* Linn. (C. & E. M. Reid 64).
1908. ? *S. websteri* Potonié (Engelhardt & Kinkelin 65).
1908. *S. aloides* Linn. (C. & E. M. Reid 66).
1909. *S. aloides* Linn. (Hartz 67).
1911. *S. aloides* Linn. (Krause 69).
1920. *S. aloides* Linn. (Menzel 72).

The description already given of the recent *S. aloides* holds good for the fossil species (see p. 118). In one particular only is there ever any difference worthy of remark. The testa of the recent *S. aloides* is invariably smooth or ornamented with very obscure ridges, and this is frequently true also of the fossil *S. aloides*; but, in addition to the smooth forms, there are other rougher ones associated with them, and in a series of fossils from a given locality it is often possible to trace every gradation between the rougher and the smoother forms. It is impossible to place a dividing-line between the two types, and to aver that here one species or variety ends and another begins (see p. 122).

Dimensions.—Length=7·2 to 9 mm.; breadth=2 to 3 mm.

Horizons.—Upper Pliocene, Pleistocene.

Localities.—Tegelen-sur-Meuse near Venloo (Limburg), Upper Pliocene (Teglian of Reid); Cromer Forest-Bed (Beeston, Pakefield, Sidestrand, and Corton), Upper Pliocene (Cromerian of Reid); South Elmham (Suffolk) (Interglacial of Reid); peat-beds of Klinge near Cottbus (Interglacial of Nehring); Jutland (Interglacial of Hartz).

Affinities.—A very close relationship exists between *S. aloides* and the Preglacial *S. intermedius*. The latter differs only in being a larger, stouter form, having a crested keel, also more pronounced and more numerous tubercles.

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EXPLANATION OF PLATES V & VI.

Plate V.

[Figs. 1–23 exteriors, 24–31 interiors of the seeds;
c=chalaza; h=hilum; k=keel; m=micropyle; t=tegmen; x=raphe.]

Fig. 1. *Stratiotes headonensis*, Lower Headon, Hordle. × 7. (See p. 125.)
2. *Stratiotes headonensis*, Lower Headon, Hordle. × 5.
3. *Stratiotes headonensis*, Lower Headon, Colwell Bay (Isle of Wight). × 5.
4. *Stratiotes neglectus*, Bembridge Marls, Hamstead Ledge (Isle of Wight). × 4. (See p. 126.)
5. *Stratiotes acuticostatus*, Hamstead Beds, Bouldnor Cliff (Isle of Wight). × 4·5. (See p. 127.)
6. *Stratiotes acuticostatus*, Hamstead Beds, Bouldnor Cliff (Isle of Wight). × 3·5.
7. *Stratiotes websteri*, Hamstead Beds, Hamstead (Isle of Wight). × 5.
8. *Stratiotes websteri*, dorsal view, Hamstead Beds, Hamstead (Isle of Wight). × 5. (See p. 128.)
9. *Stratiotes websteri*, base, Hamstead Beds, Hamstead (Isle of Wight). × 5.
10. *Stratiotes websteri*, Lignite, Bovey Tracey (Devon). × 2.
11. *Stratiotes websteri*, Lignite, Bovey Tracey (Devon). × 4.
12. *Stratiotes websteri*, *Cyrena* Marls, Offenbach-am-Main. × 4·5.
13. *Stratiotes thalictroides*, Calcaire de Beauce, Longjumeau (cast). × 4. (See p. 129.)
14. *Stratiotes thalictroides*, Calcaire de Beauce, Longjumeau (cast). × 4.
15. *Stratiotes kaltennordheimensis*, Kaltennordheim. × 4. (See p. 130.)
16. *Stratiotes tuberculatus*, lignite, Pont-de-Gail, Lower Pliocene. × 3·5.
17. *Stratiotes tuberculatus*, ventral view, lignite, Pont-de-Gail, Lower Pliocene. × 3·5. (See p. 131.)
18. *Stratiotes intermedius*, Preglacial, Eime, near Hanover. × 3.
19. *Stratiotes intermedius*, ventral view, Preglacial, Eime, near Hanover. × 3. (See p. 132.)
20. *Stratiotes aloides*, Cromer Forest-Bed, Beeston. × 3·5. (See p. 133.)
21. *Stratiotes aloides*, Pleistocene, Klinge, near Cottbus. × 3·5.
22. *Stratiotes aloides*, Pleistocene, Klinge, near Cottbus. × 3·5.
23. *Stratiotes aloides*, recent. × 3·5.
24. *Stratiotes headonensis*, Lower Headon, Hordle. × 7.
25. *Stratiotes headonensis*. Lower Headon, Hordle. × 5.
26. *Stratiotes headonensis*, Lower Headon, Colwell Bay (Isle of Wight). × 5. (See p. 125.)
27. *Stratiotes neglectus*, Bembridge Marls, Hamstead Ledge (Isle of Wight). × 4. (See p. 126.)


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M. E. J. C. DEL.

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Fig. 28. *Stratiotes neglectus*, Bembridge Marls, Hamstead Ledge (Isle of Wight). × 4.
29. *Stratiotes acuticostatus*, Hamstead Beds, Bouldnor Cliff (Isle of Wight). × 4·5. (See p. 127.)
30. *Stratiotes acuticostatus*, Hamstead Beds, Bouldnor Cliff (Isle of Wight). × 4.
31. *Stratiotes websteri*, Hamstead Beds, Hamstead (Isle of Wight). × 4.

Plate VI.

[Figs. 1–20, interior of seeds; 21–31, cell-structure.]

Fig. 1. *Stratiotes websteri*, Hamstead Beds, Hamstead (Isle of Wight). × 4.
2. *Stratiotes websteri*, lignite, Bovey Tracey (imperfect; shows raphe). × 4. (See p. 128.)
3. *Stratiotes websteri*, lignite, Bovey Tracey (imperfect; shows micropyle). × 4.
4. *Stratiotes websteri*, *Cyrena* Marls, Offenbach-am-Main. × 4.
5. *Stratiotes websteri*, *Cyrena* Marls, Offenbach-am-Main. × 2.
6. *Stratiotes thalictroides*, Calcaire de Beauce, Longjumeau (imperfect; shows micropyle). × 4. (See p. 129.)
7. *Stratiotes thalictroides*, Calcaire de Beauce, Longjumeau (restoration of interior). × 4.
8. *Stratiotes thalictroides*, Calcaire de Beauce, Longjumeau (transverse section).
9. *Stratiotes kaltennordheimensis*, Lower Miocene, Kaltennordheim. × 4.
10. *Stratiotes kaltennordheimensis*, Lower Miocene, Salzhausen. × 4.
11. *Stratiotes kaltennordheimensis*, Lower Miocene, Mosbach, Wiesbaden. × 4·5. (See p. 130.)
12. *Stratiotes tuberculatus*, Pont-de-Gail Lignite, Lower Pliocene (very oblique micropyle). × 5. (See p. 131.)
13. *Stratiotes tuberculatus*, Pont-de-Gail Lignite, Lower Pliocene (reflexed micropyle). × 4.
14. *Stratiotes tuberculatus*, Pont-de-Gail Lignite, Lower Pliocene (horizontal micropyle). × 4.
15. *Stratiotes tuberculatus*, Upper Miocene Lignite, Chambeuil (imperfect; shows micropyle).
16. *Stratiotes tuberculatus*, Upper Miocene Lignite, Chambeuil (imperfect; shows raphe).
17. *Stratiotes intermedius*, Preglacial, Eime, Hanover. × 3. (See p. 132.)
18. *Stratiotes aloides*, Cromer Forest-Bed, Beeston. × 3·5.
19. *Stratiotes aloides*, Pleistocene, St. Cross, South Elmham. × 3.
20. *Stratiotes aloides*, recent. × 3·5.
21. *Stratiotes aloides*, recent, cells of tegmen. Much magnified.
22. *Stratiotes aloides*, recent, cells of innermost layer of testa. Much magnified.

[Figs. 23–31. Cells of the interior of the keel; the external edge is always to the right, and the internal edge to the left, of the figures. All much magnified.]

23. *Stratiotes headonensis*, Lower Headon.
24. *Stratiotes neglectus*, Bembridge Marls.
25. *Stratiotes acuticostatus*, Hamstead Beds.
26. *Stratiotes websteri*, Hamstead Beds.
27. *Stratiotes kaltennordheimensis*, Lower Miocene.
28. *Stratiotes tuberculatus*, Lower Pliocene.
29. *Stratiotes intermedius*, Preglacial.
30. *Stratiotes aloides*, Pleistocene (Klinge).
31. *Stratiotes aloides*, recent.

Discussion.

Mrs. E. M. Reid stated that this was the first attempt to trace the geological history of a genus of plants through a study of fossil fruits and seeds. Owing to the comparative novelty of the subject and the few deposits examined in this way, the knowledge of the geological range of species was usually very imperfect, though a considerable amount was known of the fossil history of many genera on the botanical side. In the case of *Stratiotes* the abundance and marked character of the seeds early attracted the attention of geologists, and much material was collected. With regard to the age of the Bovey Tracey lignite, independent palæobotanical evidence supported the Author's suggestion that it was older than had hitherto been thought, but Mrs. Reid considered that our knowledge was not yet sufficient to place it definitely.

Dr. F. A. Bather, in congratulating the Author on a paper of remarkable interest most lucidly presented, enquired why a genus with so many species was called 'monotypic.' The details of the evolution suggested many thoughts; he would ask only whether the Author could suggest any adaptive cause of the continuous changes.

The Author replied that the word 'monotypic' was used as applied by botanists to the recent plant, of which there was only one living species, *S. aloides*, and that, so far as one could judge, there was no special adaptive purpose served by the evolutionary changes described in the fossils.

With regard to the Glacial Period, *Stratiotes* could furnish no new evidence: there was no decided break in the evolutionary series, and *S. aloides*, at any rate, was of little value as an index of climate, since it ranged from beyond the Arctic circle into Central Europe.

In using the term 'Preglacial' in the case of the fossils from the Cromer Forest-Bed, from Eime (near Hanover), and from Copenhagen, the Author had adopted the chronology of the late Mr. Clement Reid and of those foreign geologists who had made a special study of the beds concerned.

6. Oligocene Mosquitoes *in the* British Museum; *with a* Summary *of our present* Knowledge *concerning* Fossil Culicidæ. By Frederick Wallace Edwards, B.A. (Communicated by W. Campbell Smith, M.C., Sec.G.S. Read April 12th, 1922.)

[Plate VII.]

In 1916 Prof. T. D. A. Cockerell described some fossil mosquitoes in the United States National Museum, from the Oligocene of the Isle of Wight. The material that he described consisted only of duplicates from the Brodie Collection, the main portion of which remained in the Geological Department of the British Museum (Natural History). When Prof. Cockerell came to England in 1920, he undertook the study of the main Brodie Collection of fossil insects, and found in it a considerable number of mosquitoes; at his suggestion I readily undertook to work out this material, and I wish to express my indebtedness to him for assistance and advice. My thanks are also due to Dr. A. Smith Woodward, F.R.S. and to Dr. F. A. Bather, F.R.S., for the facilities which they have afforded me. The descriptions and figures of Cockerell not being entirely clear, Dr. Bather obtained from Dr. R. S. Bassler, of Washington, photographs of the types of Cockerell's three species. These are reproduced here (Pl. VII), and have been of great assistance in deciding upon the synonymy.

As explained by Prof. Cockerell in a recent paper, the material examined belongs in part to the British Museum and in part to the late Mr. R. W. Hooley, F.G.S. In the descriptions which follow, specimens belonging to the Museum are referred to by the letter I and their register-number, those belonging to Mr. Hooley (but deposited at the Museum) by the letter H. All the material is from Gurnet Bay (Isle of Wight) from Middle Oligocene deposits, and almost all was collected by E. J. A'Court Smith and the Rev. P. B. Brodie.

In addition to studying the Gurnet Bay material, I have searched through the whole of the Purbeck and amber collections in the British Museum, in the hope of finding mosquitoes in them, but without success. I found, however, the types of several Nematocera which have been referred to the Culicidæ, and as the study of these has yielded some interesting results, it seems worth while to make some remarks about them, and at the same time to summarize what is already known about fossil Culicidæ.

Jurassic Species.

No Culicid is definitely known from the Mesozoic as yet; the following doubtful forms may possibly belong to the family, but more probably do not.

Corethrium pertinax Westwood.[1] Lower Purbeck, Swanage (Dorset). The name implies that Westwood considered the specimen to be allied to *Corethra*, but it is almost certainly a species of *Tipula*. Only a portion of a wing is preserved.

Culex fossilis Brodie.[2] Purbeck, Vale of Wardour (Wiltshire). The type is in the British Museum; the preservation is not very good, and the characters are difficult to make out. A plumose male antenna is visible; one leg shows a small simple claw on two detached tarsal segments; the palpi are apparently short and curved. The wings are not preserved. This is most probably a Chironomid: the genus *Dara* has been founded for it by C. G. A. Giebel.[3]

Rhyphus priscus Brodie.[4] Purbeck, Vale of Wardour (Wiltshire). This is most probably not a *Rhyphus*, since the legs, so far as they can be made out, seem too long and slender. The general appearance of the specimen does not exclude the possibility that it may be a Culicid; there are obscure structures in front of the thorax in the type, which may possibly be the mouth-parts and antennæ of a mosquito, but they may also be portions of a displaced wing. Giebel has proposed the generic name *Bria* for this fossil, but there is nothing in the type by which it can be definitely assigned even to its correct family.

Eocene Species (North American).

Culex proavitus Scudder.[5] Fossil Cañon, White River (Utah), U.S.A. One badly preserved and poorly figured specimen. From the evidence presented by Scudder in his description and figure, this would not appear to belong to the Culicidæ at all. It may be a *Phlebotomus* or some other small Psychodid.

Culex damnatorum Scudder.[6] Green River (Wyoming), U.S.A. Three female specimens with short palpi (figured as a little over a quarter as long as the proboscis). Proboscis rather short, equalling the front femora in length; orbital bristles remarkably well preserved; first hind tarsal segment shorter than the tibia; tip of abdomen apparently damaged; wing-venation not preserved. Evidently a Culicine mosquito; perhaps a true *Culex*, but it cannot be definitely assigned to that genus on the information available. Probably a re-examination of the specimens would reveal other characters not mentioned by Scudder (for example, the condition of the claws might be ascertainable).

Culex winchesteri Cockerell.[7] Green River horizon, Cathedral Bluffs (Western Colorado), U.S.A. The proboscis is apparently

[1] Q. J. G. S. vol. x (1854) p. 387 & pl. xv, fig. 2.
[2] 'Fossil Insects' 1845, p. 34 & pl. iii, fig xv.
[3] 'Fauna der Vorwelt' 1856, p. 254.
[4] 'Fossil Insects' 1845, pl. iv, fig. 10.
[5] 'Tertiary Insects' 1890, p. 582 & pl. v, figs. 8–9.
[6] *Ibid.* p. 582 & pl. x, fig. 14.
[7] 'Nature' vol. ciii, p. 44 (March 1919); Proc. U.S. Nat. Mus. vol. lvii (1920) p. 248 & pl. xxxv, fig. 2.

longer than in *C. damnatorum*, and the palpi proportionately shorter (scarcely a sixth as long as the proboscis). The tip of the abdomen (female) is said to be blunt, this perhaps indicating an affinity with *Culex* rather than with *Aedes*. Wing-venation not well preserved.

Corethra exita Scudder.[1] Chagrin Valley, White River (Colorado), U.S.A. A single poor specimen, badly figured. Although referred by Scudder (with doubt) to *Corethra*, it seems possible from the statements made that this form might be a mosquito with the proboscis broken off. On the other hand, there is so little preserved that it might almost equally well be a small Tipulid.

Oligocene Species.

(*a*) Baltic Amber (Lower Oligocene).

The existence of mosquitoes (*Culex*) in Baltic amber has been mentioned by E. von Schlotheim,[2] V. de Motschulsky,[3] Otto Helm,[4] and F. Meunier,[5] but no specimen has yet been described. *Culex loewii* Giebel is referred to at the end of this paper under Quaternary species. Helm's statement, that he possessed a male and female of *C. pipiens* from amber, requires confirmation as regards the identity of the species.

Mochlonyx sepultus Meunier.[5] Evidently referred correctly by Meunier to the genus *Mochlonyx*. Another species (?) of the genus has been mentioned under the name *M. atavus* by H. Loew.[6]

Corethra ciliata Meunier.[7] Evidently a true *Chaoborus (Corethra)*. It is of interest to note that, in its small size, the specimen agrees rather with the existing Oriental than with the Palæarctic species. It would be unsafe, however, to draw any conclusion from this.

Dixa succinea Meunier[8] and *D. minuta* Meunier.[9] Both these species differ only in minor details from recent species. *D. minuta*, especially as regards the position of *r–m* before the fork of *Rs*, is not unlike *D. obscura* Loew.

(*b*) West German Paper-Coal (Upper Oligocene).

Culicites tertiarius Heyden.[10] Exact locality not stated. The type is in the British Museum (Natural History), in excellent

[1] 'Tertiary Insects' 1890, p. 583 & pl. v, figs. 22–23.
[2] 'Petrefaktenkunde Deutschlands' 1820, p. 43.
[3] Bull. Soc. Imp. Nat. Moscou, vol. xviii, pt. 2 (1845) p. 98.
[4] Schrift. Naturw. Gesellsch. Danzig, vol. ix (1896) p. 222.
[5] Revue Scient. du Bourbonnais, vol. xv (1902) p. 199.
[6] 'Ueber die Dipteren-Fauna des Bernsteins' 1861; see Handlirsch, 'Die Fossilen Insekten' vol. ii (1906–1908) p. 971. I have been unable to consult Loew's paper.
[7] Bull. Soc. Entom. France, 1904, p. 89, figs. 1–3.
[8] Ann. Sci. Nat. ser. 9, vol. iv (1906) p. 395 & pl. xvi, figs. 8–9.
[9] *Loc. cit.* fig. 7.
[10] Palæontographica, vol. x (1862) p. 79 & pl. x, fig. 30.

preservation ; there are several specimens on one slab of paper-coal, obviously pupæ of a *Chaoborus (Corethra)*. The characteristic hexagonal structure of the thoracic respiratory organs is clearly visible under a magnification of 75, and the size and general appearance is closely similar to that of the existing European species.

Culex ceyx Heyden.[1] Rott, Siebengebirge. The figure shows a female mosquito with short palpi and somewhat pointed abdomen, but the wing-venation is not indicated. It is possibly an *Aedes*. I am indebted to my friend Mr. P. H. Grimshaw for the loan of a specimen, said to be this species, from the Royal Scottish Museum, collected at Rott, the type-locality. The specimen is of little value, however, as it shows only portions of the thorax and abdomen; there is nothing to prove that it is a mosquito at all.

(*c*) Upper Oligocene of Aix-en-Provence.

Culicites depereti Meunier.[2] Although Meunier simply defines '*Culicites*' as 'with the appearance of *Culex* or *Corethra*,' his photograph shows what is obviously a typical Culicine mosquito. The wing-venation is not well shown, but some vein-scales are preserved. The specimen is a female, with palpi nearly a third as long as the proboscis. The tip of the abdomen appears to be damaged.

Eriopterites tertiaria Meunier.[3] Although Meunier states that his specimen is 'incontestablement' an *Erioptera*, he nevertheless proposes the new generic name *Eriopterites* for it. Inspection of his photograph makes it perfectly obvious that it is not a Tipulid at all, but a species of *Dixa* (possibly identical with *D. minuta* Meunier), with a venation similar to that of the recent *D. obscura* Loew and *D. clavulus* Will.

The occurrence of *Corethra* in these deposits has been mentioned by Hope.[4]

(*d*) Middle Oligocene of the Isle of Wight (Gurnet Bay).

Dixa priscula Cockerell.[5] This differs slightly from most recent species in having the cross-vein *m–cu* unusually oblique and placed somewhat before *r–m*.

AEDES PROTOLEPIS (Cockerell). (Pl. VII, figs. 2–4 & text-figs. 1–2.)

♀. *Culex protolepis* Cockerell, Proc. U.S. Nat. Mus. vol. xlix (1916) p. 488 & pl. lxii, fig. 1.

♂. *Culex petrifactellus* Cockerell, *Ibid.* p. 489 & pl. lxi, fig. 12.

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[1] Palæontographica, vol. xvii (1870) pp. 252, 266 & pl. xiv, fig. 21.
[2] Verhandl. Akad. Amsterdam, sect. 2, vol. xviii (1916) No. 5, p. 16, photo.
[3] *Ibid.* p. 15.
[4] Trans. Entom. Soc. London, vol. iv (1847) p. 252.
[5] Ann. & Mag. Nat. Hist. ser. 9, vol. vii (1921) p. 466.

In Prof. Cockerell's descriptions stress is laid on the small size of *Culex petrifactellus* in comparison with *C. protolepis*. The photographs of the types, however, show that there is really scarcely any difference in size between the two; this is, indeed, fairly obvious from the measurements given by the author. These measurements show that the wing of *C. petrifactellus* is narrower than that of *C. protolepis*, and has somewhat shorter fork-cells. Such differences are commonly associated with sex in recent mosquitoes, and it seems to be most probable that the same is true of fossil forms. In response to a query by Prof. Cockerell, Dr. Harrison G. Dyar has kindly examined the types in the Washington Museum, and informs me that, in his opinion, *C. petrifactellus* may be the male of *C. protolepis*.

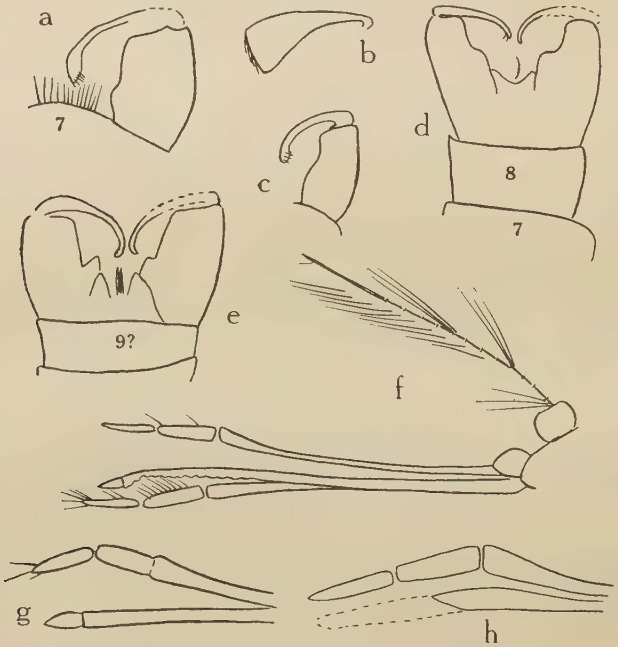
Aedes protolepis is abundantly represented in the collections in the British Museum (Natural History). Apart from 24 male and 14 female specimens which are determinable with a fair degree of probability, there are some 40 others which, although too fragmentary for positive identification, probably are most of them, if not all, examples of *A. protolepis*. The following descriptive notes are based on a comparison of all these specimens. There are very few that are well preserved in more than one part, and it is not easy to correlate with certainty the different parts and the two sexes.

Size.—The wing-length varies from 3·2 to 4 mm., female wings being on the average slightly longer. The average full length of the body is about 5 mm. The abdomen alone varies in length from 2·5 to 3·5 mm., most specimens (whether male or female) measuring about 3 mm.

Male head.—A number of specimens shows the plumose antennæ, the two long terminal segments having only a basal hair-whorl, as in recent mosquitoes. The proboscis is slender, scarcely, if at all, swollen at the tip, about 3 mm. long (thus equalling the abdomen); the labella are of normal size. The palpi are very slightly longer than the proboscis, exceeding the latter in length by less than half the length of the terminal segment. The long segment is about two and a half times as long as the two terminal segments together, and distinctly swollen on its apical fifth. The last two segments are bent gently downwards, as in *Ochlerotatus*. The penultimate segment is equal in diameter to the tip of the long segment, but tapers somewhat apically. The terminal segment is equal in length to the penultimate, and distinctly more slender, its tip being more or less pointed. In the best specimen (one of two males lying close together on a small block, I. 9620) the last two segments of one palpus are rather conspicuously hairy; in other less perfectly preserved examples these segments appear to be either bare (I. 10074), or carry a few apical hairs on the terminal segment only (I. 8986). In one of these (I. 10074) the palpi appear to be considerably longer than the proboscis, but this is almost certainly due to the fact that the apical portion of the proboscis is broken off.

Female head.—Two specimens (I. 17164 & I. 9993) show the palpi and proboscis well. The proboscis is about 2·7 mm. in length, and distinctly shorter than the abdomen (which in I. 17164 is 3·2 mm. long). The palpi are one-fifth as long as the proboscis, and apparently two-segmented, the second being 1·7 times as long as the first. A third specimen (H. 468) is considerably shorter (proboscis, 2 mm.; abdomen, 2·2 mm), and the second segment of the palpi seems relatively somewhat shorter; this may possibly represent another species. Another specimen (I. 20561) shows a portion of an antenna, and in this the second segment of the palpi is also shorter, 1·5 times the length of the first.

Fig. 1.—Aedes protolepis (*Cockerell*), ♂.



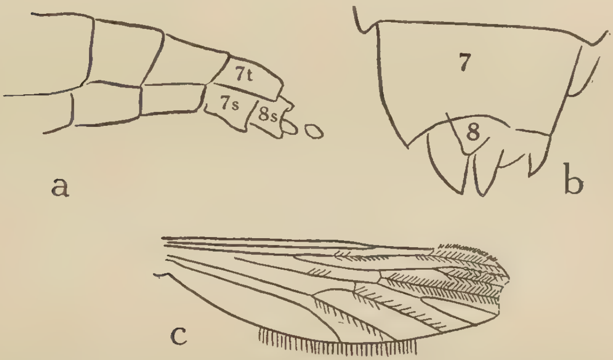
[All × 37, except *f*, which is × 22.]

a, hypopygium, I. 17069, showing several short bristles at the tip of the clasper; 7, seventh sternite with terminal row of bristles. *b*, approximate shape of clasper in end view (in all the specimens examined the clasper was seen edgewise, or in section only). *c*, hypopygium, I. 9404; small specimen. *d*, hypopygium, I. 8986; claspers apparently more slender apically than in *a* and *c*, but this is probably owing to the position of preservation; 7, 8, seventh and eighth abdominal segments. *e*, hypopygium, I. 10074, showing traces of internal organs, perhaps tenth sternites; 9 ?, perhaps ninth tergite. *f*, mouth-parts and antennæ, I. 9629, showing hairs, etc. (see also photograph); the hypopygium of this specimen is like that of I. 10074. *g*, tip of proboscis and palpus, I. 8986. *h*, tip of palpus, I. 10074; the tip of the proboscis is broken off.

Thorax.—This shows no striking peculiarities. In shape it appears to resemble closely that of modern Culicine mosquitoes.

Male abdomen.—Rather short and plump, the eighth segment reduced as in recent mosquitoes, short and broad, the hypopygium large. The form of the hypopygium looks rather different in the various specimens; but this probably is merely due to the manner of preservation, and to different portions being shown in different examples. There are a dozen or more specimens which show the organ fairly well. The side-pieces are very stout, less than twice as long as their breadth at the base, and apparently provided with large basal lobes; the apex also is quite broad (not at all pointed),

Fig. 2.—Aedes protolepis (*Cockerell*).



a, tip of abdomen of ♀, H. 468, × 30: side view, 7t, seventh tergite; 7s & 8s, seventh and eighth sternites. A part of one of the cerci (apparently) is detached. *b*, tip of abdomen of ♀, I. 17148, × 50: showing the seventh and eighth segments and pointed cerci in dorsal view. *c*, loose wing, I. 9754, × 14: wing-scales remarkably well preserved.

although it does not seem that a definite apical lobe is present. The claspers are well developed, articulated at the outer apical corner of the side-piece, and curved inwards somewhat. They evidently were very strongly chitinized structures. In dorsal view they generally appear to be of almost even breadth, if anything slightly tapering towards the tip; but in a number of specimens a careful examination clearly shows that they are broadly expanded apically in a vertical plane. Probably this is the case in all, but it is not always apparent; and it is possible, therefore, that there may be two species in the series. The tip of the clasper in some specimens (I. 17069, I. 9404) shows a row of several short bristles. The anal and genital parts are not sufficiently well preserved to permit of their structure being made out.

Female abdomen.—Somewhat pointed, but not conspicuously so, especially when the eighth segment is retracted (as is the case in several specimens: I. 20561, I. 8996, I. 17148, etc.). When

the abdomen is fully extended (I. 17147, H. 468), the eighth segment (especially the sternite) is seen to be quite large. Several specimens (I. 17147, I. 17148, I. 20561) show well-marked pointed cerci.

Legs.—Very few examples show any remnant of the legs, and the few that do (I. 10068, I. 9685, I. 9454) have not the claws or terminal tarsal segments preserved. These do, however, show traces of scales on the legs. In one (I. 9454), which has the hind legs preserved, it is unfortunately not possible to determine the length of the first tarsal segment. Another fragmentary specimen (I. 10068), probably of this species, shows the tibia and first tarsal segment of one hind (?) leg, the latter being a little shorter than the former. The front femur and tibia are fairly long, equal in length.

Wings.—These show no divergence from recent species. As mentioned above, the wings in some specimens are rather narrower, and their fork-cells relatively shorter than in others. These are probably males. A few (I. 9072, etc.) show traces of the vein-scales, much as figured by Cockerell, and many have the fringe-scales distinct. Two specimens (I. 9753 and I. 9754, each represented by one wing only) have the vein-scales exceptionally well preserved; they are seemingly rather longer and narrower than in some examples which have only a few remaining, but are most likely the same species, the difference probably being only apparent. The upper fork-cell has its base slightly distal to that of the lower, and is a very little longer than its stem. The mediastinal vein (*Sc*) ends in the costa immediately above the base of the third longitudinal vein (R_{4+5}) or very little beyond it. The cross-veins are separated by rather more than the length of the posterior (I. 9221, I. 9140), or by almost double the length of the posterior (I. 9754).

From the foregoing description it will be clear that the species is not a true *Culex*, but belongs to the genus *Aedes* in the broad sense. The form of the male palpi, the pointed female cerci, the retractile tip of the female abdomen, and the wing-venation, all point to this conclusion. It is very desirable, however, that we should be able to go farther than this, and ascertain (if possible) the position of the species within the genus *Aedes*. Recent work has shown that, while the male palpi may be valuable in this respect, the most reliable indications of relationship are to be found in the genital structures of both sexes. According to Dyar[1] two main groups of the genus *Aedes* are indicated by the structure of the male hypopygium: (1) The first group is characterized by the presence of claspettes (harpagones); in this group the claspers are of minor functional and taxonomic importance, and are almost always slender, lightly chitinized, with a single terminal spine. In this group the subgenus *Ochlerotatus* includes the great majority of the Holarctic forms, and extends through South

[1] 'Insecutor Inscitiæ Menstruus' vol. vi (1918) pp. 71–86.

America into Australia; the subgenus *Finlaya* is cosmopolitan, with its centre in the Indo-Malayan region. (2) In the second group there are no claspettes, and the claspers are generally better developed, more highly chitinized, of greater functional importance and specific diversity. This group is characteristic of the tropics of the Old World (Oriental and Ethiopian regions); several subgenera occur which are interrelated in a complex manner.

The strongly developed claspers and the apparent absence of claspettes of the male *A. protolepis* show that this species almost certainly belongs to the second group, although it cannot be referred exactly to any modern subgenus. The stumpy abdomen and short hypopygium of the male are suggestive of *Aedes* in the restricted sense, although the male palpi are those of *Aedimorphus* [*Ecculex*]. The large eighth segment of the female, together with the well-developed cerci, are suggestive of either *Aedes* or *Armigeres*.

There is only one representative of the second group of *Aedes* at present occurring in Britain (*A. vexans* Meigen). It is probable, therefore, that *A. protolepis* should be regarded as evidence of the existence of an Oriental or Ethiopian type of Culicid fauna in these islands in early Tertiary times. This, of course, is entirely in accord with the general evidence afforded by fossils of other groups. Unfortunately, the fossils provide no evidence as to the time or place of origin of the present Palæarctic fauna, which may or may not have existed here in the Oligocene Period.

Aedes (?) sp.

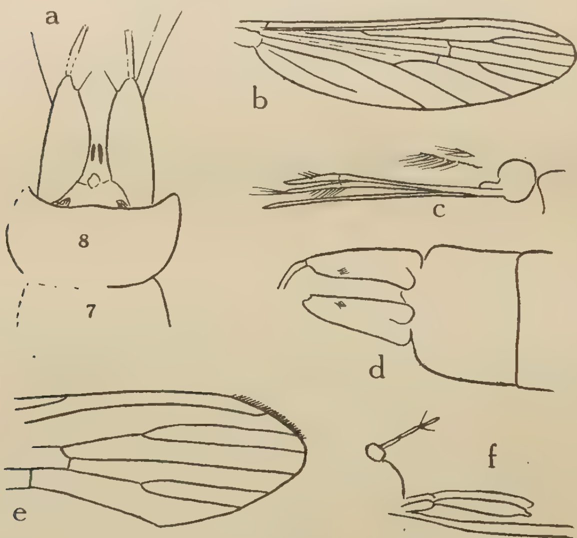
One male specimen (I. 10261) apparently represents a species distinct from *A. protolepis*, since the palpi are (unless broken) a little shorter than the proboscis, and distinctly more hairy than in any undoubted *A. protolepis*. They resemble the palpi of I. 10272 (regarded as *Culex protorhinus*), but the specimen is much smaller than any of those described under this name. The tip of the abdomen is missing. The specimen is of interest, because it shows very distinctly the hair-scars on the abdominal tergites, and also minute densely crowded punctures on the sternites which may represent the points of attachment of the scales. Apart from this example, I have seen no clear evidence of the existence of abdominal scales, although I have mounted scraps of the actual abdominal integument and examined them under a high power. It is, however, certain from the appearances on some of the fossils that the palpi and legs bore scales, and it may therefore be regarded as probable that these were carried by the abdomen also. Most of the Lepidopterous wings in the collection are perfectly denuded, and show no trace of scaling.

CULEX PROTORHINUS Cockerell. (Pl. VII, figs. 1, 5, 7 & text-fig. 3.)

♂. *Culex protorhinus* Cockerell, Proc. U.S. Nat. Mus. vol. xlix (1916) p. 488 & pl. lxii, fig. 2.

According to Prof. Cockerell's description, which is supported by Dr. R. S. Bassler's photograph, the type of *C. protorhinus* is distinctly larger than that of *A. protolepis.* It is a male of which only the head and thorax, portions of the proboscis and one antenna, and the first few segments of the unbanded abdomen are visible. It is, therefore, quite impossible to compare it satisfactorily with any other specimen, except in regard to its size, unless the palpi or the tip of the abdomen can be dug out. From the nature of the specimen, as shown by the photograph, this could probably not be done.

Fig. 3.—Culex protorhinus *Cockerell (?).*



a, tip of abdomen of ♂, I. 17138, × 37 : 7 & 8, seventh and eighth segments. The claspers are incomplete at the base and tip. *b*, loose wing, H. 463, × 10 : no scales preserved. *c*, *d*, head and tip of abdomen of ♂, I. 10272 : *c* × 22, *d* × 37. *e*, tip of wing of ♀, I. 9408, × 22 : a few fringe-scales are visible. *f*, palpi and base of proboscis and antenna of ♀, H. 540, × 22 : the palpi show some indication of a minute terminal segment.

There are eight specimens in the British Museum Collection, and six others in the Hooley Collection, which seem distinctly larger than any *A. protolepis,* and differ from it in various other respects. Although it is improbable that these all belong to the same species, they may be referred provisionally to *Culex*

protorhinus. It is certain that few, if any, of them can belong to the genus *Culex* in the modern sense; some seem rather to indicate a connexion with *Aedes*, others perhaps with *Theobaldia*, or even with *Megarhinus*; but it will probably be best to refrain from attempting to place them generically. The best-preserved of the specimens are described separately below.

I. 10272.—A male in good preservation, but without legs or wings. Length of abdomen = 4·2 mm.; proboscis = 3·7 mm.; palpi = 3·3 mm. Although the palpi appear to be distinctly shorter than the proboscis, it is just possible that the tip is missing in both; the joints are not clearly marked. The tip of the long segment is slightly swollen, the terminal segment or segments slightly bent down, slightly swollen, and conspicuously hairy. Portions of the antennæ are plainly visible. The abdomen is seen in dorsal view, and is more conspicuously banded than is the case in most examples of *A. protolepis*, owing doubtless to the bases of the segments being less strongly chitinized than the apices and therefore appearing paler. There is no definite trace of scaling, or even of hair-bases. The eighth segment is damaged, but evidently very large. The side-pieces of the hypopygium are long and pointed, almost three times as long as their breadth at the base, apparently provided with small distinct basal lobes, and each showing a dark spot before the tip which is somewhat suggestive of the subapical prominence of *Theobaldia*. At the tip of one side-piece the base of the clasper is visible. Unfortunately, the specimen is chipped just at this point.

I. 17138.—A male abdomen only, 4·8 mm. long and even more conspicuously banded than that of I. 10272. The eighth segment is very broad, much broader than the hypopygium, and distinctly broader than the seventh segment (thus recalling *Megarhinus*). The side-pieces are long, pointed, somewhat swollen in the middle, and on the inside before the tip have each a hair apparently arising from a slight prominence. Portions of the claspers are present.

I. 9771.—A male abdomen, 4 mm. long, with part of the thorax and a fragment of one wing. The abdomen is unbanded; the side-pieces are long and pointed, shaped much as in I. 10272. Claspers not visible.

I. 8921.—A body of a male, lying full length in ventral view, 8 mm. in total length (abdomen, 5·5 mm.). Traces of the plumose antennæ and of the base of the proboscis fix the specimen definitely as a male Culicid. The thorax is partly flattened; in front are a pair of flat areas which may be the prothoracic lobes: if so, they are large, and meet in the middle line. The abdomen is conspicuously banded. The eighth segment is narrower than the seventh, and not much broader than the hypopygium. The side-pieces are shaped much as in I. 17138, but the slight subapical prominences are a little farther removed from the tip.

I. 9052.—A female abdomen, 4 mm. long, with portions of the thorax and wings. The abdomen is distinctly banded, the eighth segment large (both tergite and sternite?), and the cerci appear to be short and rounded (but are perhaps damaged).

I. 17146.—A female; body damaged (abdomen, 4 mm.); one wing well preserved (4·5 mm. long), showing the fringe-scales of the posterior border particularly well. Venation as in I. 9408.

I. 9408.—A female showing one wing fairly well preserved, also the palpi. The fork-cells are rather long, their bases almost level, the upper one fully twice as long as its stem. *Sc* ending above the base of R_{4+5}. Cross-veins separated by nearly twice the length of the posterior. Second segment of palpi a little less than twice as long as the first. The abdomen, as in a few specimens of *A. protolepis*, shows a bronzy lustre, probably due to chemical change. There is a faint suggestion of abdominal scaling. Perhaps this and I. 17146 may be females of *A. protolepis*, but they seem to be distinct from I. 17164 and I. 9993, which have been regarded as females of that species.

I. 9206.—Two damaged specimens on one block, with a venation (as far as traceable) like that of the above two specimens. One shows a few wing-scales fairly clearly.

H. 540.—A female, the wings and tip of the abdomen poorly preserved. The basal half of one antenna is present, also the palpi and the base of the proboscis. The palpi are rather long, the second segment practically twice as long as the first, and showing traces of a small nipple-like segment at its tip. On the same block is a pupa, probably of a species of *Simulium*. H. 419 shows similar female palpi.

I. 9893.—The body of a female. Total length = about 6·5 mm.; abdomen, 4·5 mm. The specimen is flattened sideways, the abdomen fully extended, tapering somewhat. Eighth segment large. Cerci not visible (damaged in digging out). Palpi with the second segment not quite so elongate as in H. 540 and H. 419, also somewhat stouter.

H. 463.—A beautifully-preserved loose wing (4·3 mm. long) which does not, however, show any trace of scaling. The fork-cells are both long, the upper with its base slightly distal to that of the lower, and almost exactly twice as long as its stem; its branches are parallel. *Sc* ends above the base of R_{4+5}. Cross-veins separated by scarcely the length of the posterior.

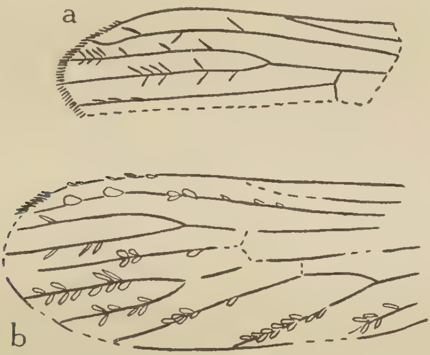
H. 1014.—A loose wing, not very well preserved, 5·2 mm. long. Fork-cells both long; the upper has its base slightly but distinctly proximal to that of the lower, its branches parallel. A crack in the specimen obscures the position of the cross-veins.

CULEX VECTENSIS, sp. nov. (Text-fig. 4.)

One specimen (a female, I. 9324) is clearly distinct by venation from *A. protolepis* and is too small for *C. protorhinus*; though imperfect, it shows sufficient characters to warrant description.

The palpi are well preserved, the second segment being about 1·6 times as long as the first, and slightly stouter; there is no trace of a small terminal segment. Only the base of the proboscis is visible. Several antennal segments are present, and show the normal structure. The abdomen has the tip missing. Only a portion of one wing is present, but this shows the most important points. *Sc* is long, ending considerably beyond the base of R_{4+5}

Fig. 4.—*Apical part of wing* (a) *of* Culex vectensis, *sp. nov.*; *and* (b) *of* Tæniorhynchus cockerelli, *sp. nov.* × 22.



and immediately above the base of R_2. The upper fork-cell is very long, almost three times as long as its stem; the lower fork-cell is missing. The upper fork-cell shows a number of long, linear scales. The length of the portion of wing preserved is 1·6 mm.; the whole wing would be about 3 mm. long.

The length of *Sc* and of the upper fork-cell points to the strong probability that this is a species of *Culex* in the modern sense. In living *Aedes*, *Sc* seldom extends beyond the apex of *Rs*, and the upper fork-cell is nearly always shorter.

TÆNIORHYNCHUS (?) COCKERELLI, sp. nov. (Text-fig. 4.)

There are two blocks (I. 10106 and I. 17190) of a female of another distinct species; one block is the counterpart of the other, but through unequal damage the left wing is better preserved on one block and the right wing on the other. The state of preservation is rather poor, but the following points can be made out:—

Length of body = 4·8 mm.; length of proboscis = 2·2 mm.;

palpi = 0·5 mm.; wing, from base of fork of *Cu* to wing-tip, 1·8 mm. The joints of the palpi are obscure, and the relative lengths of the segments cannot be made out satisfactorily. In the wings the positions of the cross-veins and of the tip of *Sc* are difficult to make out; *Sc* appears to end almost immediately above the base of *Rs*, and the cross-veins are perhaps separated by about twice the length of the posterior (in one wing they cannot be made out at all). The fork-cells are long, their bases almost level, the upper one apparently about 2·5 times as long as its stalk. On many of the veins scattered scales remain, and these are nearly all rather broad, very distinctly broader than those of any other specimen examined. Some of those on the fork-cells, however, are narrower than the others. No definite characters can be seen in the thorax or abdomen.

This specimen is provisionally referred to the genus *Tæniorhynchus* on account of the broad wing-scales, but it should be remembered that among recent species those belonging to various genera (for instance, *Aedes* or *Culex*) may develop broad scales on the wings. The true location of this fossil species is, therefore, not satisfactorily determined. It would probably be too much to hope that the minute adult characters (other than those of the wing-scales) on which the definition of the genus *Tæniorhynchus* is based should be preserved in any fossil. The specimen under notice, however, is interesting as showing that *Tæniorhynchus* may have existed side by side with *Culex* and *Aedes* (and perhaps other Culicine genera) so far back as the Oligocene Period.

Culicid Pupa.

On one slab of rock (I. 20561), besides several specimens of *Aedes protolepis* and a number of other insects, there is a specimen of a mosquito pupa—possibly, from its rather large size, *Culex protorhinus*. The thoracic respiratory organs are not preserved, nor can the form of the paddles be made out.

No trace of a larva was met with in the Isle of Wight material. Several specimens were labelled 'gnat larva' by the collectors; but these all proved on examination to be abdomens of mosquitoes or other insects.

Miocene Species.

No Culicidæ have been recorded, but the British Museum possesses a male *Chaoborus* (*Corethra*) in Burmese amber. In size and appearance it differs little from the small species at present existing in India. The tips of the abdomen, wings, and legs are missing, and the specimen is therefore hardly fit to describe.

Palæolycus problematicus Etheridge & Olliff.[1] Fox & Partridge's Claim, Red Hill, near Emmaville, New England (New

[1] Mem. Geol. Surv. N.S.W. vol. vii (1890) p. 11 & pl. i, figs. 10–14.

South Wales). Upper Tertiary. Though this form was described as a Coleopterous larva, it has been suggested by A. Handlirsch[1] that it is more probably Dipterous, and perhaps a Culicid. I do not consider that this view has much justification, although the figures seem to suggest a slight possibility that it may be a Tipulid larva of the tribe Pediciini.

Quaternary Species.

The following mosquitoes have been recorded from copal:—

Culex ciliaris (Linn.) Bloch.[2] Locality not stated.

Culex flavus Gistl.[3] Brazil. 'C. totus flavus, thorace lineis duabus lateralibus, antennis pedibusque atris; alis immaculatis. Minor *C. pipiente* Fabr. cui proxime affinis.'

Culex loewii Giebel.[4] Locality not stated. Described as from amber, but Klebs[5] says that it was actually in gum-copal. The specimen is described as black, with a silvery Λ in front of the mesonotum, the second segment of the tarsi yellowish. Neither this nor *C. flavus* Gistl can be positively identified with recent species from the short descriptions given.

In conclusion, it may be remarked that the most interesting result of the study of the fossil Culicidæ so far discovered is the knowledge gained that probably all the main divisions of the family existed in mid-Tertiary times much as they do to-day, and with almost identical characters. Not only are the subfamilies Dixinæ, Chaoborinæ, and Culicinæ represented and defined as sharply as they are now, but there was then also a clear division of the Chaoborinæ into *Chaoborus* and *Mochlonyx*, and the main lines of evolution of the Culicinæ were also well indicated. Although no fossil *Anopheles* has yet been found, there can be no doubt from its morphology that this is also an old genus, most probably older than any Culicine form; its non-occurrence in the fossil state can be accounted for by supposing that it has always been, as it is now, less abundant than the Culicinæ. The origin and phylogenetic history of the Culicidæ must go back well into the Mesozoic Era; and, from the small size and fragile nature of the insects, it is probably too much to hope that we can ever obtain much direct palæontological evidence on these matters.

[1] 'Die Fossilen Insekten' 1906–1908, p. 972.
[2] Beschäft. Gesellsch. Naturforsch. Freunde Berlin, vol. ii (1776) p. 164.
[3] 'Isis' 1831, p. 247.
[4] Zeitschr. Gesellsch. Naturw. vol. xx (1862) p. 317.
[5] Schrift. Phys.-Œkon. Gesellsch. Königsberg, vol. li (1910) p. 220.

EXPLANATION OF PLATE VII.

[Figs. 1–4 by H. G. Herring; 5–7 by Dr. R. S. Bassler.]

Fig. 1. *Culex protorhinus* Cockerell? I. 10272. A male showing mouth-parts, banded abdomen, and hypopygium. See also text-fig. 3, *c* & *d*. The proboscis and palpi were further exposed after the photograph was taken. × 4. (See p. 148.)

2. *Aedes protolepis* (Cockerell). I. 9754. Well-preserved wing (probably female) showing vein-scales. See also text-fig. 2 *c* (p. 145). × 4. (See p. 142.)

3. *Aedes protolepis* (Cockerell). I. 17164. Female showing proboscis, palpi, and pointed abdomen. × 10.

4. *Aedes protolepis* (Cockerell). I. 9629. Male showing mouth-parts and antennæ. The photograph does not bring out the hairs on the palpi, which are well preserved in the specimen and are shown in text-fig. 1 *f* (p. 144). × 10.

5. *Culex protorhinus* Cockerell. Type. × 6.

6. *Culex petrifactellus* Cockerell. Type. × 6.

7. *Culex protolepis* Cockerell. Type. × 6.

Discussion.

Dr. F. A. Bather said that the Geological Department of the British Museum considered itself most fortunate in having its specimens of fossil mosquitoes studied by such an expert as the Author. It had been very difficult to persuade entomologists to deal with the obscure and imperfect remains that too often represented fossil insects; but a beginning had been made, and to the Author and others they were very grateful. In attempting to account for the rich and varied insect-fauna of the Gurnet-Bay Oligocene, someone had imagined poisonous gases rising from submarine fumaroles and stupefying the insects that flew over the lagoon. What did the Author think of that?

Mr. A. H. Williams remarked that he understood that the vast numbers of mosquitoes in the far North depended upon vegetation, whereas the Author appeared to imply that mosquitoes generally were dependent on animal life.

Dr. W. D. Lang joined with the former speakers in congratulating the Author on his illuminating paper. He wished to draw attention to what he thought was a significant fact brought out in the paper, namely, that each of the three Culicine genera found in the Oligocene represented one of three groups of Culicine mosquitoes occurring at the present day. These groups had been determined in recent species, as now in fossil forms, by imaginal characters. But the speaker had elsewhere shown that the recent British Culicines fell into the same three categories on larval characters also, even on those of the first instar; and that therefore the three groups diverged early in Culicine phylogeny — a suggestion now corroborated by the appearance of all three as far back as the Oligocene.

Dr. Marie Stopes said that this interesting account of fossil mosquitoes reminded her of some Japanese fossil mosquitoes

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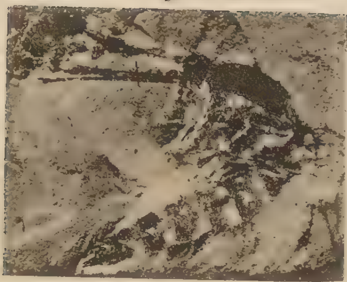

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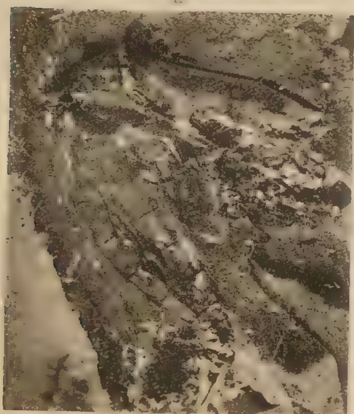

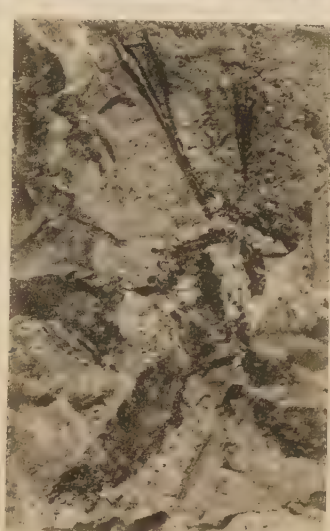

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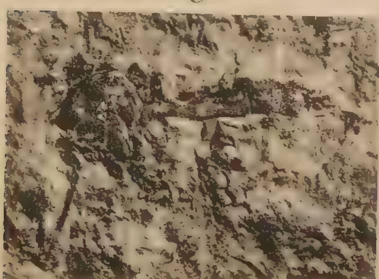

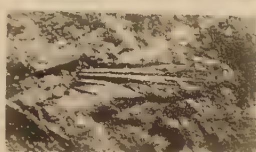

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7

H.G.H. & R.S.B. PHOTO.

CULEX AND AEDES.

which she herself had found in a very fine-grained deposit containing exquisitely-preserved plant-remains. The mode of preservation and general conditions of the strata seemed to indicate that there were times when these fossil insects did not come by their deaths in the way implied by Dr. Bather, but that probably in such freshwater deposits they accumulated more or less naturally as a result of sudden puffs of wind throwing the mosquitoes on to the water, their wings becoming entangled in the water-surface, and after drowning they ultimately sank as would any other waterlogged débris. The fossil insects in her possession were not in the condition of 'bran-mash' fragments as those so generally described, but were remarkably perfect, with stretched wings attached to the bodies, and legs hanging as though they were floating through the air.

The AUTHOR, in reply, said that he did not think that fossil mosquitoes could be used satisfactorily as indices of climate, the differences between Arctic and tropical species being too slight. The Isle-of-Wight insects were perhaps drowned in a small lake and blown to the edge (as frequently happens now), and probably were quickly covered. It was doubtless true that the adults of many mosquitoes fed on vegetable substances, and could exist without blood; but mosquitoes with bloodsucking habits might have existed before mammals were developed, since at the present day birds, reptiles, and even amphibians were attacked by some species of mosquitoes.

7. *On some* RUGOSE CORALS *from the* BURINDI SERIES (LOWER CARBONIFEROUS) *of* NEW SOUTH WALES; *together with a* SHORT ACCOUNT *of the* UPPER PALÆOZOIC ROCKS *of the* AREA *in which they were collected.*

By Prof. WILLIAM NOEL BENSON, B.A., D.Sc., F.G.S., and STANLEY SMITH, M.A., D.Sc., F.G.S. (Read June 14th, 1922.)

[PLATES VIII & IX.]

CONTENTS.

I. INTRODUCTION.

HOMŒOMORPHY, regarding both external form and internal structures, is exceedingly common among Rugose Corals. Analogous features may occur in unrelated genera living contemporaneously in the same region or may be found reappearing in corals of different stocks in widely separated regions and epochs.

This paper describes two genera—*Amygdalophyllum* Dun & Benson, and *Cionodendron*, gen. nov., from the Burindi Series (Lower Carboniferous) of New South Wales; it also includes a few remarks concerning the species of *Lithostrotion* collected from the same series (and from the equivalent horizon in Queensland).

Amygdalophyllum and *Cionodendron* are related respectively to the Carboniferous species of '*Cyathophyllum*' (*Palæosmilia*) Edwards & Haime,[1] and *Lithostrotion*; but both corals are characterized by an unusually large columella, as in *Cyathaxonia*. *Amygdalophyllum* and *Cionodendron* illustrate a remarkable case of parallelism.

The Australian species of *Lithostrotion* show certain small peculiarities of structure which distinguish them as a group from their British congeners.

The described material, much of which has been collected by one of us (W. N. B.), is the property of the Geological Surveys of New South Wales and Queensland, and of the Australian Museum (Sydney), and our thanks to these Institutions for the loan of the small collection is cordially tendered.

Before the corals are discussed, a short account is given of the stratigraphical succession of the region in which they were found, and our reasons are stated for correlating the Burindi Series with the Viséan of Europe.

[1] Ann. Sci. Nat. ser. 3, vol. x (1848) p. 261.

II. The Upper Palæozoic Rocks of North-Eastern New South Wales.

The fossils herein described come from the parishes of Moorowarra and Babbinboon, near Somerton, 20 miles north-west of Tamworth, and 200 miles north of Sydney; from the head of Hall's Creek near Bingara, 60 miles farther north; and from Slaughterhouse Creek, 40 miles still farther north-north-west. These localities lie on the western foothills of the plateau of New England, which forms the north-eastern portion of New South Wales.

The entire foothill region forms the northern portion of the 'Great Serpentine Belt.' The geological structure of this region was outlined by one of us in 1913,[1] and described in greater detail for certain areas (1913–1920).[2] Briefly stated, the stratigraphical succession consists of a great thickness (possibly 5000 feet) of Middle Devonian radiolarian claystones with three limestone horizons containing corals, and with much intercalated igneous material—felspathic tuffs and spilitic, doleritic, and keratophyric rocks. The fossils of these and of all other Devonian rocks of Australia have been recently enumerated and discussed by the same author.[3]

This, the Tamworth Series, is followed by the Barraba Mudstones, a thick series of mudstones with interbedded tuffs and occasional vast masses of volcanic agglomerate. Except for the presence of *Lepidodendron australe* M'Coy (also present in the Middle Devonian claystones) and radiolaria, the series is unfossiliferous. The Barraba Mudstones are probably Upper Devonian, but may extend into the Lower Carboniferous. They are succeeded without recognizable break by the Burindi Series, although it is possible that an unconformity may be present here, as has been recently stated by Mr. C. A. Süssmilch.[4] The Burindi Series consists of olive-coloured mudstones, tuffs, and a few lenticular masses of oolitic or crinoidal limestone yielding a few corals: from these was obtained a large fauna, including most of the fossils here discussed. In this series *Lepidodendron australe* M'Coy has been replaced by *L. veltheimianum* Sternberg. The total thickness of the Barraba and Burindi Mudstones is indefinite, but may be over 5000 feet. The Burindi Series seems to belong to the higher part of the Lower Carboniferous, and the evidence upon which this correlation is made is discussed later.

It is followed, again without apparent unconformity, by the

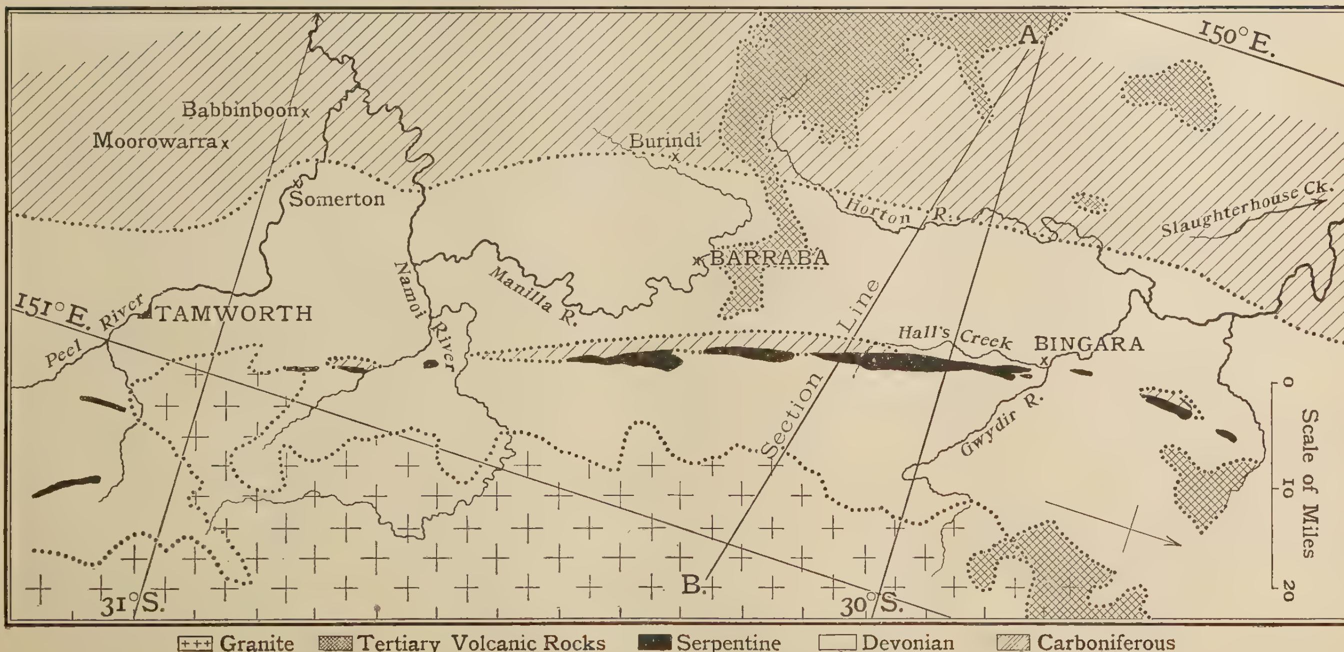
[1] Geol. Mag. 1913, pp. 17–21.

[2] Proc. Linn. Soc. N.S.W. vol. xxxviii (1913) pp. 490–517 & 569–96; *ibid.* vol. xl (1915) pp. 540–624; *ibid.* vol. xlii (1917) pp. 223–45, 250–83, & 693–700; *ibid.* vol. xliii (1918) pp. 320–84; *ibid.* vol. xlv (1920) pp. 285–316.

[3] 'Materials for the Study of the Devonian Palæontology of Australia' Rec. Geol. Surv. N.S.W. vol. x, pt. 2 (1922) pp. 83–204.

[4] Journ. & Proc. Roy. Soc. N.S.W. vol. lv (1921) p. 250.

Fig. 1.—*Diagrammatic geological map of the Great Serpentine Belt of New South Wales.*



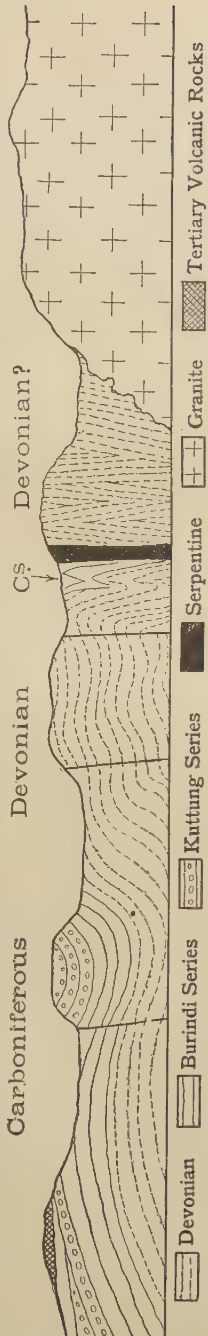


Fig. 2.—*Geological section across the Great Serpentine Belt of New South Wales (along A–B in fig. 1, p. 158).*

Kuttung Series—some 10,000 feet of acid felsitic tuffs, fluvioglacial conglomerates, tillites with rarely striated pebbles, and seasonally banded contorted 'varve' rocks, andesitic and rhyolitic flows, and intrusive rocks represented by felsitic and other sills.

This series was originally termed by one of us (W. N. B.) the 'Rocky Creek Series', but has since been more appropriately named the Kuttung Series by Prof. Sir T. Edgeworth David & Mr. C. A. Süssmilch,[1] after their important investigation of the southern continuation of these rocks in the Newcastle district, 100 miles beyond the region here considered. In the Newcastle district the Kuttung Series represents, in all probability, the Middle Carboniferous, and is followed by the so-called 'Permo-Carboniferous System,'—the Lower and Upper Marine Formations, and the Coal Measures. The relationship of the Permo-Carboniferous to the Carboniferous proper has been discussed by Sir Edgeworth David in the paper already cited, who concluded that the former was chiefly of Permian age, although the basal part was probably coeval with the Upper Carboniferous (Uralian) rock elsewhere and generally rests unconformably upon the Middle Carboniferous beds.

In the region here considered, these marine Permo-Carboniferous rocks are not present, although there is a small development of the Coal Measures lying unconformably upon the Kuttung Conglomerate. There are in this area minor developments of Jurassic sandstone and of Tertiary gravels and volcanic rocks, but discussion of these hardly lies within the scope of this paper.

The Devonian and Carboniferous rocks have been greatly folded. The former (see fig. 2) occur in a series of tightly packed and broken folds lying west of the great composite granite-batholith of New England, which has invaded them. The highly folded rocks are separated from the less folded strata farther

[1] Journ. & Proc. Roy. Soc. N.S.W. vol. liii (1919) pp. 246–338.

west by an almost meridional and remarkably continuous fault. This fault formed the channel along which has flowed the peridotite, now converted into serpentine. Adjacent to the serpentine sheet the folds of the Devonian are closely packed, although they show little overfolding, but farther west they pass into gentler flexures. Long, narrow, doubtless synclinal strips of Carboniferous rocks have been nipped into the folded Devonian beds near the serpentine, and in one of these strips the fossils from Hall's Creek (see figs. 1 & 2, pp. 158, 159) were found. The chief development of the fossiliferous Lower Carboniferous rocks, however, forms a broad synclinal zone running parallel to the serpentine-belt, and 20 miles west of it, and in the axis of this syncline rises a ridge of the Kuttung rocks. The locality, Slaughterhouse Creek, is on the eastern flank of the syncline, and near the northern margin of our area (see fig. 1, p. 158). The type-locality Burindi is also on the eastern flank, 60 miles south of Slaughterhouse Creek, and Moorowarra and Babbinboon lie 40 miles still farther south, Moorowarra being on the eastern flank of the syncline and Babbinboon on the western.

It is not possible as yet to divide the marine Carboniferous sediments into faunal or lithological zones, nor do the conditions seem such as would promise much success if an attempt were made. While we may, therefore, consider that the last four localities mentioned are situated approximately on the same formation, the thickness of which may be measured in thousands of feet, it is only by inference that we may group with them the fossiliferous beds at Hall's Creek. The description of the Burindi fauna has been the work chiefly of Prof. L. G. De Koninck, Robert Etheridge, Junr., Mr. W. S. Dun, and Mr. J. Mitchell, and ourselves, and our knowledge concerning it has recently been summarized by one of us.[1] It consists of about 300 species, principally corals, bryozoa, brachiopods, molluscs, and trilobites, other groups being sparsely represented. It forms quite a representative development of the Culm fauna, and the affinities of the majority of the species are with Eurasiatic types, showing very little in common with the Carboniferous faunas of America. It contains a small proportion of forms which seem to be modifications of the Upper Devonian littoral fauna that is developed in the central, southern, and western parts of New South Wales; but no characteristic Tournaisian forms have been found. The whole fauna, indeed, seems to be of Viséan age, and the Burindi Series should, therefore, be referred to the higher part of the Lower Carboniferous. There are no forms that characterize the Upper Carboniferous, such as *Fusulina*, found in Eastern Asia; and there is very little affinity with the succeeding 'Permo-Carboniferous' marine fauna, the origin of which and its relationship to the Burindi fauna has been discussed by Sir T. W. Edgeworth David (*op. jam cit.*).

Summarizing the foregoing remarks, we may re-state the general

[1] W. N. Benson, 'A Census & Index of the Lower Carboniferous Burindi Fauna' Rec. Geol. Surv. N.S.W. vol. x, pt. 1 (1921) pp. 12–74.

succession of the formations and their correlation with the Upper Palæozoic rocks of Europe in the following synopsis :—

'Permo-Carboniferous System.' (Hunter River Series.)	PERMIAN and (?) UPPER CARBONIFEROUS.
Unconformity.	
Kuttung Series. Conglomerates, etc.	MIDDLE CARBONIFEROUS.
Conformity.	
Burindi Series. Mudstones, etc.	LOWER CARBONIFEROUS=VISÉAN.
Apparent conformity,	but possible non-sequence.
Barraba Series. Mudstones and tuffs.	UPPER DEVONIAN, but possibly extending into LOWER CARBONIFEROUS.
Conformity.	
Tamworth Series. Radiolarian claystones, tuffs, limestone, etc.	MIDDLE DEVONIAN.

III. *AMYGDALOPHYLLUM*, Dun & Benson, 1920.

[Proc. Linn. Soc. N.S.W. vol. xlv, pp. 339–41.]

Simple coral. The corallum has the usual horn-shaped form (turbinate to cylindrical) common to most solitary Rugose Corals. The septa are both numerous and long,[1] and fine dissepimental tissue builds up a wide extrathecal area.[2] The distinguishing character of the genus is the remarkably large solid columella.

Genotype. *Amygdalophyllum etheridgei*; no other species of the genus is yet known.

AMYGDALOPHYLLUM ETHERIDGEI Dun & Benson. (Pl. VIII, figs. 1–3; Pl. IX, fig. 2.)

1920. *Amygdalophyllum etheridgei* Dun & Benson, Proc. Linn. Soc. N.S.W. vol. xlv, pp. 339–41 & pl. xviii, figs. 2–6; *non* fig. 1.[3]
1921. *Amygdalophyllum etheridgei* Dun & Benson, Rec. Geol. Surv. N.S.W. vol. x, p. 34.

'*Koninckophyllum*' *inopinatum* Etheridge fil.; Geol. Surv. Queensl. Bull. 12 (1900) pp. 21–22, pl. i, fig. 2 & pl. ii, figs. 9–10, very closely approaches *A. etheridgei*, and is in all probability congeneric with that species. The forms agree in the type of the columella, in their numerous septa, and in their wide development of fine dissepiments. '*K.*' *inopinatum* differs from *A. etheridgei* in the major septa not reaching the columella, and in the minor septa attaining only half the length of the major.

[1] The descriptive terms long and short, here used in reference to septa, denote their character as seen in transverse section.

[2] The theca is the annular wall formed by the innermost layer of dissepiments against which the tabulæ abut; see Q. J. G. S. vol. lxxi (1915–16) p. 228. This wall divides the corallite into an intrathecal and an extrathecal area.

[3] The coral figured in the original description to illustrate external form (pl. xviii, fig. 1) was found when cut to be a specimen of *Zaphrentis sumphuens* Etheridge fil., which it externally resembles.

Morphology.

Habit of growth and external form.—Little need be added to the statements made in defining the genus. The corals were all weathered and otherwise imperfect; 8 to 10 cm. may have been the original length of the largest of them, and the greatest diameter measured was about 4 cm. It is not improbable that larger examples may be found. None of the specimens exhibited a calice.

Internal structure [ephebic stage].—Septa. In sections 4 cm. in diameter there are approximately 60 septa in each of the two cycles. The septa may remain united to the epitheca, or become separated from this enclosing wall and in some cases leave quite a wide area between it and their outer ends (Pl. VIII, fig. 1: upper part of figure). The major septa penetrate the columella, but the minor, which are about two-thirds as long as the major, do not reach the axis. The septa are thus numerous and crowded, and display a pseudo-radial symmetry; the cardinal fossula (although not conspicuous) can be distinctly recognized (in Pl. VIII, figs. 1 & 3, and Pl. IX, fig. 2). Alar septa cannot be located in section; but their position is discernible on the sides of the corallum.

Columella.—The large columella is the most distinctive feature of the genus. It is elliptical and cuspidate in section; the approximate ratio of the longer axis to the shorter ranges from 1 : 0·5 to 1 : 0·75 (the former being about 9 mm. in length, and the latter 5 to 6·5 mm.). The cusp projects into the cardinal fossula. It has a fibrous structure presenting a feather-like appearance in longitudinal section (Pl. VIII, fig. 2), and a radial and concentric one in transverse section (Pl. IX, fig. 2). It is built up of slightly curved conical layers superimposed one upon the other. Within this columella are seen in transverse section a short medial plate and the inner ends of the major septa. The medial plate is very distinct in most sections examined; but it varies in length in the different specimens: in no case, however, does it completely bisect the structure (see Pl. VIII, fig. 1 & Pl. IX, fig. 2). In the latter figure it is seen to be in continuity with the cardinal septum. It may be noted also, though less distinctly, in Pl. VIII, fig. 3.

The major septa reach the medial plate, although they are not easily traced through the columella. They are there obscured by the fibrous texture of the columella itself, and are difficult to follow on account of their twisted nature; it is possible, nevertheless, to distinguish them when the section is carefully examined with a lens. Pl. VIII, fig. 1 illustrates the columellar structure above described fairly clearly.

A few minor septa may also, it is possible, be represented by the lamellæ within the columella, as in *Carruthersella* and *Ciononden-dron* (p. 164), although, as is also the case in these genera, the minor septa do not themselves reach the solid axis.

Tabulae.—The tabulæ are represented by small, strongly arched plates—the tabellæ[1] (Pl. VIII, fig. 2). The area occupied by the tabular tissue is a comparatively narrow one, the intrathecal region being largely taken up by the columella.

Dissepiments.—The dissepiments are very small and very strongly arched, and in the adult stage build up a wide extrathecal region constituting as much as three-quarters of the radius of the corallum.

Epitheca.—This wall is thin, and is therefore readily destroyed by erosion or exposure.

Ontogeny.

Unfortunately, in none of the collected specimens are the initial stages of the corallum preserved. The 'proximal end' is missing in every case. The earliest section examined (which was approximately 12·5 mm.) represented quite a late neanic stage: at this stage the columella has attained its characteristic form and proportion; but the dissepimental tissue is undeveloped, and the septa are united to a stout epitheca. While the major septa (about 30 in number) reach the columella, the minor are merely rudimentary, not being more than 1 mm. in length. The coral at this stage somewhat resembles *Cyathaxonia*.

As the corallum develops, the septa become reduced at the then 'outer ends' (where they join the epitheca) to a mere lamella, and may finally become entirely separated from this outer wall.

Affinity and Comparisons.

Amygdalophyllum etheridgei is very similar to '*Cyathophyllum*' (*Palæosmilia*) *murchisoni* Edwards & Haime in all its structural details, except in the development of a columella, and there can be little doubt that the former species is a modification of the latter. The numerous slender septa,[2] the extensive development of dissepimental tissue forming a wide extrathecal region, and the tendency towards the separation of the septa and epitheca are the same in the two genera. In both cases, moreover, the major septa meet at the centre of the corallum, and their inner ends are more or less twisted; but, while in *Palæosmilia murchisoni* the inner ends of the septa are free, in *Amygdalophyllum etheridgei* these are embedded in a true columella. Sections of *Palæosmilia murchisoni* and *Amygdalophyllum etheridgei* are (for comparison) shown close to each other in Pl. IX, figs. 1 & 2.

It may be mentioned here that the columellæ of Rugose Corals originate as a dilation of the middle region of the axial septum,

[1] S. Smith, Q. J. G. S. vol. lxxi (1915–16) p. 225.

[2] In corals in which there are comparatively few septa, the septa and epitheca are relatively thick; in forms having numerous septa, the septa and epitheca are thin.

before or after this divides into the cardinal and counter-septa.[1] In some cases the columella remains united to both septa,[1] in others, to either the counter or cardinal septum; while, in yet other instances, it becomes separated from both septa.[2] The medial plate, as in *Amygdalophyllam*, represents part of the original axial septum.

The columella in *Amygdalophyllum* is very much larger than is normally found in Rugose Corals; but three other genera are known to us which have columellæ of a similar type: namely, *Cyathaxonia*, *Carruthersella*, and *Cionodendron*.

Cyathaxonia Michelin,[3] a simple Zaphrentoid coral of which several species have been described, gives its name to the highest of the Avonian zones established by Arthur Vaughan in the British Isles. It is widely spread in Britain, and is also found in the Tournaisian of Belgium. The genus was discussed by Mr. R. G. Carruthers in 1910.[4] According to his figures, the columella has the same radial and concentric structures as that of *Amygdalophyllum*, but the septa do not enter it.

Carruthersella compacta is also a simple form, and was described by Prof. E. J. Garwood.[5] It appears to be allied to the Clisiophyllid genera. The columella contains a medial plate and embedded ends of septa; it is described by Prof. Garwood as

> 'solid and conspicuously spindle-shaped . . . composed of a narrow plate from which radiate . . .[6] closely packed lamellæ, usually in contact throughout this area: the majority of these lamellæ are directly continuous with the attenuated ends of the major septa; occasionally, additional lamellæ appear to be inserted, and occupy positions facing the minor septa, but these do not as a rule reach the central plate.'

These words equally well describe the columella of *Amygdalophyllum* and *Cionodendron*. *Carruthersella* was obtained from the Tournaisian rocks[7] of the North-West of England (Meathop Fell, near Arnside, Morecambe Bay). *Cionodendron columen*, the species to be described later, is a composite form derived from *Lithostrotion*. It is, broadly speaking, from the same region and horizon as *Amygdalophyllum*, although not from exactly the same locality, nor necessarily from precisely the same stratigraphical

[1] In previous studies (Q. J. G. S. vol. lxxi, 1915–16, p. 231, and elsewhere) one of us (S. S.) has spoken of the columella as derived from the counter-septum; this is not invariably so, and the emendation here made appears to accord more closely with the facts ascertained.

[2] Frequently, however, the union between the columella and the septa or septum is only maintained by an exceedingly thin isthmus of tissue.

[3] Congrès de Turin, 1840.

[4] Geol. Mag. pp. 53–56, & pl. iii, figs. 4–10.

[5] Q. J. G. S. vol. lxviii (1912) pp. 555–56 & pl. xlviii, figs. 1 *a*–1 *d*.

[6] The three words omitted after 'radiate' are 'fifteen to twenty'; but the figures show about this number of lamellæ on both sides of the medial plate: that is, double the number.

[7] From the summit of the *Seminula-gregaria* subzone (upper part of the *Athyris-glabristria* Zone) of Prof. E. J. Garwood, a horizon equivalent to the lower part of the Upper *Syringothyris* Zone (C_2) of Arthur Vaughan.

level. In proportion to its size, *Cionodendron* has an even larger columella than *Amygdalophyllum*; but the entire corallite of the former is smaller than the columella of the latter.

Locality.

The specimens of *Amygdalophyllum* were obtained at Babbinboon from the mudstones of the Burindi Series. They were collected by Mrs. Scott and one of us (W. N. B.). Associated with them was *Zaphrentis sumphuens* Etheridge fil.,[1] which very closely resembled *Amygdalophyllum etheridgei* in size and external form.

The type-material is in the collection of the New South Wales Geological Survey; but some sections cut from these have been placed in the British Museum (Natural History).[2]

IV. *Cionodendron*, gen. nov.

Composite genus, allied to and derived from *Lithostrotion*. In habit, form, and in general structure it is identical with the parent genus; but it is distinguished from *Lithostrotion* by the excessively large and well-formed columella, similar to that found in *Amygdalophyllum*. In *Cionodendron*, the columella occupies more than one-fourth of the diameter of the corallite.

Genotype. *Cionodendron columen*. This species is the only one at present known.

Cionodendron columen, gen. et sp. nov. (Pl. VIII, figs. 4 & 5; Pl. IX, figs. 4 & 7.)

1895. *Diphyphyllum*. Ann. Rep. Dept. Mines N.S.W. p. 188.
1921. *Diphyphyllum* Benson. Rec. Geol. Surv. N.S.W. vol. x, p. 32.

Morphology.

Habit of growth and external form.—The corallum is compound and fasciculate; the corallites are cylindrical, straight, closely grouped, and frequently touching. Diameter=5 to 6 mm.

The calice (if we judge from the sections, as no weathered calices are shown in the specimen) is probably deep and thin-walled, with a prominent boss rising from the centre.

Internal structure [ephebic stage].—Septa. About 26 septa are present in each cycle. They are united to the epitheca throughout, and the major penetrate the columella. The minor septa attain approximately half the length of the major, and thus extend well beyond the theca.

The columella is nearly circular in section, and attains a diameter of 1·5 mm. (or even a little more): that is, a fourth to a

[1] Mem. Geol. Surv. N.S.W., Palæontology, No. 5, pt. 1, p. 16 & pl. xi, figs. 4–6.

[2] R 22072 & R 21997. R 22072 was cut from the holotype now in Sydney.

third of the diameter of the corallite. In its microscopical structure the columella is very similar to that of *Amygdalophyllum* (p. 162). Within this solid axis there is buried a short medial plate, and the inner ends of the major septa which extend to the plate. Very occasionally, additional lamellæ are inserted between the embedded ends of the major septa; these lamellæ correspond in position to the minor septa, although the two are not connected.

The general structure of the columella is exhibited fairly well by the corallite lettered *d* in Pl. VIII, fig. 5; but in most corallites recrystallization has obscured the structure to some extent.

Tabulae.—The tabulæ, for the greater part, extend from the theca to the columella, but are bent irregularly and at high angles both towards the theca and towards the columella (Pl. IX, fig. 7). There is no great development of tabellæ like that seen in the *Lithostrotion* from the same region.

Ontogeny.

In the figure of *.ionodendron* (Pl. VIII, fig. 5) several stages in the development of the corallite are illustrated: these are lettered *a*, *b*, *c*, and *d*.

a (1 mm. in diameter) represents a very early neanic stage. There are only about twelve major septa present, and one of these—the cardinal or the counter-septum—is dilated to form a conspicuous columella; the other septa join the columella, as in later stages. The minor septa are very short, and the dissepimental tissue is undeveloped. The pinnate symmetry is distinct.

b (2 mm. in diameter) shows the corallite at a later neanic stage. The septa have increased in number, the minor septa are well developed, and an extrathecal area is added. The columella is not conspicuously large or well formed, and at this stage *Cionodendron* is not markedly differentiated from *Lithostrotion*. A pinnate symmetry is still discernible.

c (3 mm. in diameter). The corallite has practically attained its ephebic characters, although it has only reached half (or little more than half) of its mature dimensions. The inner ends of the major septa have gradually been enclosed by an expanding columella.

d. Ephebic stage.

Affinity and Comparison.

Cionodendron columen is a species of the Lithostrotiontidæ; but, in view of the character of the columella, we may fairly assign to it generic rank, and so mark it off from the more usual forms of *Lithostrotion*. Apart from the columella, and in a less degree in the character of the tabulæ, its form and structures are essentially those of *Lithostrotion*. As may be expected, it resembles more

closely the Australian species than it does the British. In Pl. IX are reproduced side by side for comparison longitudinal sections of *L. martini* from Settle, England (fig. 5), *L. stanvellense* from Rockhampton, Queensland (fig. 6), and *C. columen* (fig. 7). Figs. 5 & 6 are twice and fig. 7 three times the natural size.

The intermediate character of the Australian species is readily observed. The Australian species of *Lithostrotion* to which *C. columen* most closely approaches in the size of its corallite is *L. arundineum* Etheridge fil., which averages 4 to 5 mm. in diameter.

Locality.

The holotype was found in Slaughterhouse Creek, near Gravesend (N.S.W.); but an isolated corallite associated with the *Diphyphyllum* mentioned on p. 168 was obtained from the parish of Moorowarra, near Somerton (N.S.W.), The type-specimen was originally a small group of corallites about 5 or 6 cm. long and perhaps 4 cm. in cross-section. From this specimen a series of sections have been cut. The type-material[1] is in the collection of the Geological Survey of New South Wales; but some sections[2] have also been deposited in the British Museum (Natural History).

V. *Lithostrotion* Fleming, 1828.

['A History of British Animals' p. 508. Genotype: *L. striatum* Fleming, *loc. cit.* = *Astræa basaltiformis* Conybeare & Phillips, 1822, 'Outlines of the Geology of England & Wales' p. 359; = *Madrepora vorticalis* Parkinson, 1808, 'Organic Remains' p. 45 & pl. v, figs. 3, 6; = *Lithostrotion sive Basaltes minus striatum et stellatum* Lhwyd, 1699, 'Lithophylacii Britannici Ichnographia' p. 125 & pl. xxiii.]

Compound coral; the corallum may be fasciculate or massive, and accordingly the corallites are cylindrical or prismatic. The number of septa and the complexity of structure are proportional to the size attained by the particular 'species.'

In the more typical forms of *Lithostrotion* the following structures are to be found:—the septa are united to the epitheca; the major septa reach the columella, but the minor extend only a short distance beyond the theca. The fossulæ are inconspicuous. The columella is usually well developed. The tabulæ are also generally well-formed conical plates, often extending from the columella to the theca. The dissepiments are small, uniform, and in large 'species' build up a wide extrathecal area.

The individual members of the genus exhibit, however, great variation, and departure in one respect or another from the more characteristic form is frequently found.

A variation, common in the fasciculate colonies but rare in the massive, is a shortness (as seen in transverse section) of all the septa: the major as well as the minor extending inwards little beyond the theca. There is no columella, and consequently the

[1] G. S. Reg. 1464.
[2] R 21999 & R 22000–01, each cut from the holotype.

tabulæ are flat or saucer-shaped instead of conical. Such forms are usually described as *Diphyphyllum*, following Lonsdale [1]; nevertheless, both the '*Lithostrotion*' and the '*Diphyphyllum*' types of corallite may be found within the same corallum.

The characters of this well-known genus are here re-defined, merely in order to curtail the description of the Australian species, and to render a comparison between them and the British clearer and more concise.

Species of *Lithostrotion* described from the Burindi Series.

Two fasciculate and one massive species of '*Lithostrotion*' [2] and a '*Diphyphyllum*' [2&3] have been recorded from the Burindi Series. The fasciculate specimens of *Lithostrotion* have been identified [4] with species described by Robert Etheridge fil.[5] from beds in Queensland—the Star Series, in all probability stratigraphically equivalent to the Burindi Series: namely, *L. arundineum* Etheridge fil. and *L. stanvellense* Etheridge fil. The massive form was recorded by one of us (*loc. cit.*) as *L. columnare* Etheridge fil.; but the material was not available for later detailed examination.

The following remarks are based upon the examination of material from both New South Wales and Queensland.

L. arundineum is fasciculate. The corallite attains a diameter of 5 mm. and the intrathecal region of the corallite a diameter of 4 mm. The septa usually number 18 to 20 in each cycle. The species, in these respects, agrees very closely with *L. irregulare* Phillips.

L. stanvellense is fasciculate; the diameter of the corallite = 9 to 11 mm.; the diameter of the intrathecal region = 7 to 8 mm. Number of septa in each cycle, 24 to 30. Species comparable with *L. martini* Edwards & Haime.

L. columnare is massive; diameter of corallite = about 15 mm. or more; diameter of intrathecal region = 5 mm.[6] Number of septa in each cycle, about 24. Species comparable with *L. basaltiforme* auctt.

[1] 'Description of some Palæozoic Corals of Russia': see R. I. Murchison & others, 'The Geology of Russia in Europe & the Ural Mountains' vol. i (1845) pp. 602 *et seqq.*

[2] W. N. Benson, 'A Census & Index of the Lower Carboniferous Burindi Fauna' Rec. Geol. Surv. N.S.W. vol. x (1921) pp. 32 & 33.

[3] W. N. Benson & W. S. Dun, 'The Geology & Petrology of the Great Serpentine-Belt of New South Wales' Proc. Linn. Soc. N.S.W. vol. xlv (1920) p. 341.

[4] S. Smith, 'On *Aphrophyllum hallense* gen. et sp. nov. & *Lithostrotion* from the Neighbourhood of Bingara (N.S.W.)' Journ. & Proc. Roy. Soc. N.S.W. vol. liv (1920) pp. 56–63 & pls. iii–v.

[5] R. Etheridge fil., 'Corals from the Coral Limestone of Lion Creek, Stanwell, near Rockhampton' Geol. Surv. Queensl. Bull. 12 (1900) pp. 10–20 & pl. i, figs. 1, 3, 4, 5, pl. ii. figs. 1–8.

[6] The extrathecal region is always wider in 'massive' species than in fasciculate; see Q. J. G. S. vol. lxxii (1916–17) p. 282.

The Australian species, as a whole, differ from the British species in the following characters:—

(1) Columella. This is usually very much stouter than in British species (Pl. IX, figs. 3 & 6).
(2) Tabulae. The tabulæ in the Australian species are, to a great extent, replaced by strongly-arched tabellæ, or are sharply bent as in *Cionodendron* (Pl. IX, fig. 6).
(3) Septa. The septa exhibit a marked tendency to become disunited to the epitheca in the adult stage.
(4) Dissepiments. Dependent upon the disruption between the septa and the epitheca, the external dissepiments (not being intersected by the septa) frequently form an outer zone entirely built up of coarse dissepimental tissue, as in *Lonsdaleia* [1] (Pl. IX, fig. 3, corallite *b*).

It is the prevalence and the combination of these characters, and not the presence of any one of them, that distinguishes the Australian from the British forms, since in the less typical examples among the British species such features may occasionally be noted.

The occurrence of a non-columellate form among the Australian members of the genus, in which the columella is usually so pronounced a feature, is of considerable interest.

A specimen of '*Diphyphyllum*' [2] was included in the collection examined. It came from the parish of Moorowarra near Somerton, and consisted of a large number of broken and isolated corallites embedded in limestone.

This form calls for no special comment; it very closely approximates to '*D.*' *lateseptatum* M'Coy, and suggests a non-columellate specimen of *L. arundineum*. Diameter of corallite = 5·5 mm. Number of septa, about 18 to 20. Tabulæ fairly widely spaced.

Among these broken corallites of '*Diphyphyllum*' one solitary corallite of *Cionodendron* was observed, and has been previously mentioned (p. 167).

EXPLANATION OF PLATES VIII & IX.

Plate VIII.

Amygdalophyllum and *Cionodendron*.

Fig. 1. *Amygdalophyllum etheridgei* Dun & Benson. Burindi Series, Babbinboon (N.S.W.). Transverse section, × 2. The character and structure of the columella is here well shown; note that the dissepimental tissue in the upper part of the figure is not traversed by septa. F in figs. 1 & 3 indicates the position of the cardinal fossula.

2. The same. Longitudinal section, × 2. The fibrous structure of the columella, the tabellæ, and the wide zone of dissepiments (extrathecal region) are clearly illustrated by this figure. (See p. 162.)

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[1] S. Smith, Q. J. G. S. vol. lxxi (1915–16) p. 228.

[2] No 4510 or 4515, Coll. Geol. Surv. N.S.W. Sections R 20872 & R 21998, British Museum (Natural History).

Fig. 3. *Amygdalophyllum etheridgei.* Transverse section, natural size. In this specimen, the septa to the right of the figure have been crushed and broken against the columella. Similarly, in fig. 2, the tabellæ on the right of the columella are in a crushed condition. These injuries have undoubtedly been effected after the corals had been incorporated in the rock. (See p. 162.)

4. *Cionodendron columen*, gen. et sp. nov. Slaughterhouse Creek, near Gravesend (N.S.W.). Transverse section, natural size. (See p. 165.)

5. The same. Transverse section, × 3. a = neanic stage, earliest observed; b = neanic stage, later; c = neanic stage, still later; d = ephebic stage. Reference to the lettered corallites will be found on p. 166. The structure of the columella is well shown in corallite d.

[The longitudinal section of *Cionodendron columen* is shown in the next plate (fig. 7). All the sections of this coral were cut from the holotype.]

Plate IX.

Palæosmilia, *Amygdalophyllum*, *Lithostrotion*, and *Cionodendron*.

Fig. 1. *Cyathophyllum (Palæosmilia) murchisoni* Edwards & Haime. Viséan (South-West of England); a specimen in the British Museum (R 17225). Transverse section, × 1·3. This figure is included for the purposes of comparison with *Amygdalophyllum* (fig. 2). In the number and length of septa, and in the wide development of dissepimental tissue, the two genera are similar. (See p. 163.)

2. *Amygdalophyllum etheridgei* Dun & Benson. Burindi Series, Babbinboon (N.S.W.). Transverse section, ×1·3. F in figs. 1 & 2 indicates the position of the cardinal fossula. (See p. 163.)

3. *Lithostrotion stanvellense* Etheridge fil. Burindi Series, neighbourhood of Bingara (N.S.W.). Transverse section, × 2. Note the large columella, particularly in corallite a, and also the wide zone of dissepiments unintersected by septa in corallite b recalling the extrathecal region of *Lonsdaleia*. (See p. 168.)

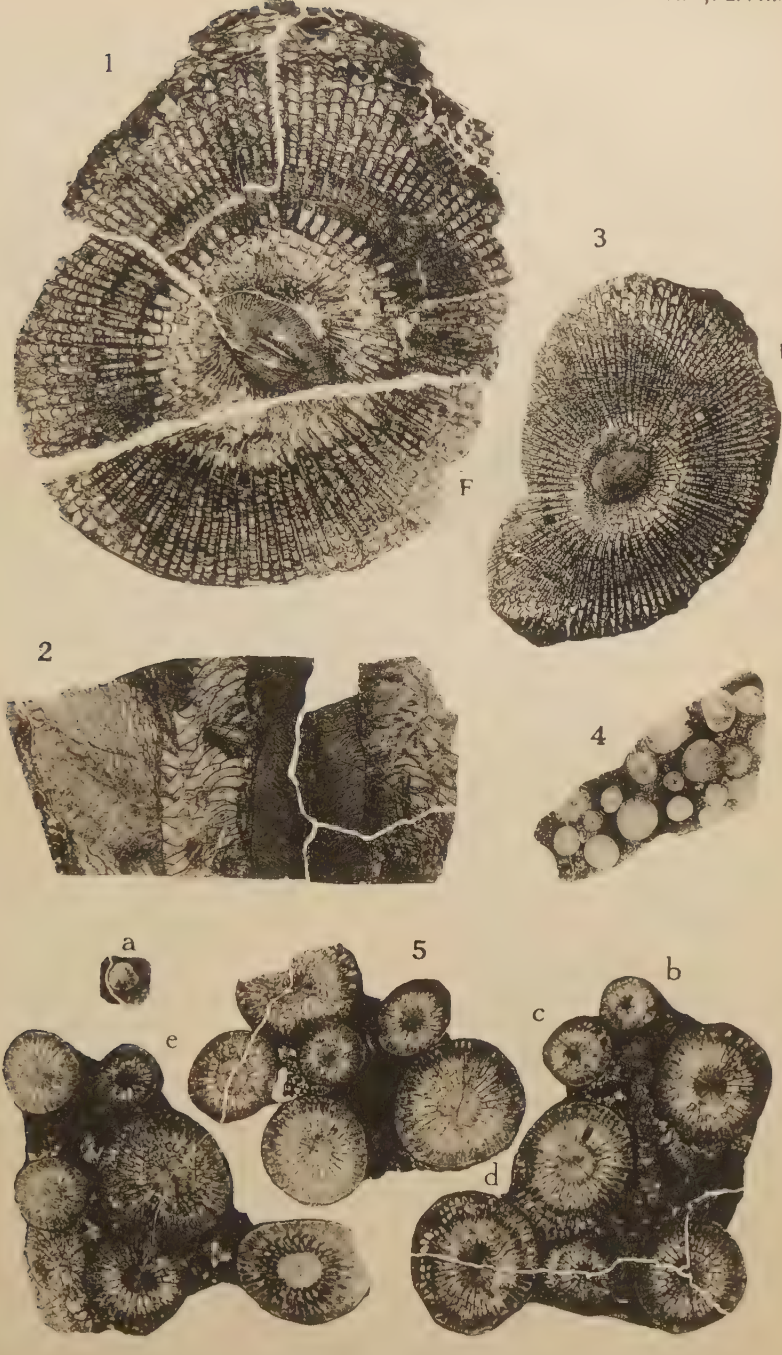
4. *Cionodendron columen*, gen. et sp. nov. Burindi Series, Slaughterhouse Creek, near Gravesend (N.S.W.). Transverse section, × 3. A few corallites from the same section as Pl. VIII, fig. 5: here included for purposes of comparison and contrast with *Lithostrotion*. (See p. 166.)

5. *Lithostrotion martini* Edwards & Haime. Viséan, Settle (Yorkshire). Longitudinal section, × 2. (See p. 167.)

6. *Lithostrotion stanvellense* Etheridge fil. Lower Carboniferous, Lion Creek, Stanwell, near Rockhampton (Queensland). Longitudinal section, × 2. (See pp. 167, 168.)

7. *Cionodendron columen*, gen. et sp. nov. Burindi Series, Slaughterhouse Creek, near Gravesend (N.S.W.). Longitudinal section, × 3. Figs. 5, 6, & 7 are arranged so as to show the differences between the typical British and typical Australian forms of *Lithostrotion* and between these and *Cionodendron*. *L. martini* has a slender columella and well-formed tabulæ; *L. stanvellense* has a stout columella, sharply bent tabulæ, and small arched tabellæ; and *Cionodendron* has a very stout columella, and concave but very sharply bent tabulæ. (See p. 167.)

[The sections reproduced as figs. 1 & 2 in Pl. VIII were irreparably broken in transit through the post. The other sections are in the custody of the institutions to which belongs the original material whence they were prepared.]



W. TAMS, PHOTO.

AMYGDALOPHYLLUM AND CIONODENDRON.

Discussion.

Prof. H. L. Hawkins congratulated the Authors on the addition of a fresh case to the growing volume of evidence regarding synchronous parallelism in evolution. With respect to the hypertrophied columellæ of the two new genera, he enquired whether there was evidence to show reason for such a development. Voluminous deposition of calcite was often a symptom of phylogerontic stages, but seemed to be induced occasionally by environment. Was the peculiarity of these corals to be ascribed to life in 'calcareous' surroundings, or was it due to phyletic senility? If the latter were the explanation, it was peculiarly interesting to find end-forms of such distinct lineages appearing at the same time in the same district, while series of the same lineages were still flourishing elsewhere.

Dr. Stanley Smith replied that he considered that the excessive deposition of calcite to form the columella was rather due to phylogerontic reasons than to excess of calcium carbonate in the sea. The conditions of deposition were not excessively calcareous, rather the reverse. He pointed out, however, that the tissue other than the columella was not particularly thicker, as is often the case where an organism shows more than usually a tendency to deposit calcium carbonate.

8. *The* Petrology *of the* Metamorphosed Rocks *of the* Start Area (South Devon). By Cecil Edgar Tilley, Ph.D., B.Sc., A.I.C., F.G.S. (Read June 28th, 1922.)

[Plates X & XI.]

Contents.

I. Introduction.

The narrow strip of country forming the southernmost peninsula of South Devon, and extending from Start Point westwards to Bolt Tail, has been the subject of repeated enquiry by various geologists since the first report on the geology of Devon by Sedgwick & Murchison.

On the north this area is bounded by rocks the Devonian age of which is attested by definite organic remains. Whether the rocks of the Start peninsula themselves are also of this age, or whether an older group, has been much discussed, and no small part of the literature is devoted to this subject, apart from any exhaustive study of the rocks themselves. Prof. T. G. Bonney [1] appears to have been the first to apply microscopic petrographic methods to the elucidation of the rocks themselves, and, following him, Miss C. A. Raisin [2] has also contributed researches on the same

[1] Q. J. G. S. vol. xl (1884) pp. 1–26.
[2] *Ibid.* vol. xliii (1887) pp. 715–33.

lines. But no adequate account of the mineralogical nature of the peculiar Green Schists of the area was forthcoming until Sir Jethro Teall and Dr. A. Harker[1] examined sections of the rocks collected by other observers.

In any interpretation of the structure of this tract of country, the early observers were at a disadvantage, in the fact that no adequate geological survey of the district had been made. The task of mapping the area was undertaken by the Geological Survey, the results appearing in the 1-inch map by W. A. E. Ussher, published in 1898. Since that date the area has been mapped on the 6-inch scale, and in 1904 Ussher's investigations appeared in the form of a memoir.[2] With this memoir the long line of publications on the Start rocks was completed, and no further data seem to have been recorded in print.

The results and conclusions to which Ussher was led are stated in his memoir, and he appended thereto a bibliography on the geology of the region, rendering it unnecessary to repeat this here. The same observer dealt with the relations of the Start group of rocks to the undoubted Devonian rocks on the north, but left undecided the mutual relations of these groups. Beyond petrographic descriptions of a few rocks by Sir Jethro Teall, the petrology of the area, and more particularly the nature of the Green Schists, which form so prominent a group in the Start stratigraphy, are but lightly touched upon in the official memoir.

The purpose of the present communication is the treatment of these rocks from the petrological point of view; but it is necessary, for the sake of completeness, to remark again on the stratigraphy, and discuss Ussher's interpretation of the structural relations.

II. Structure of the District.

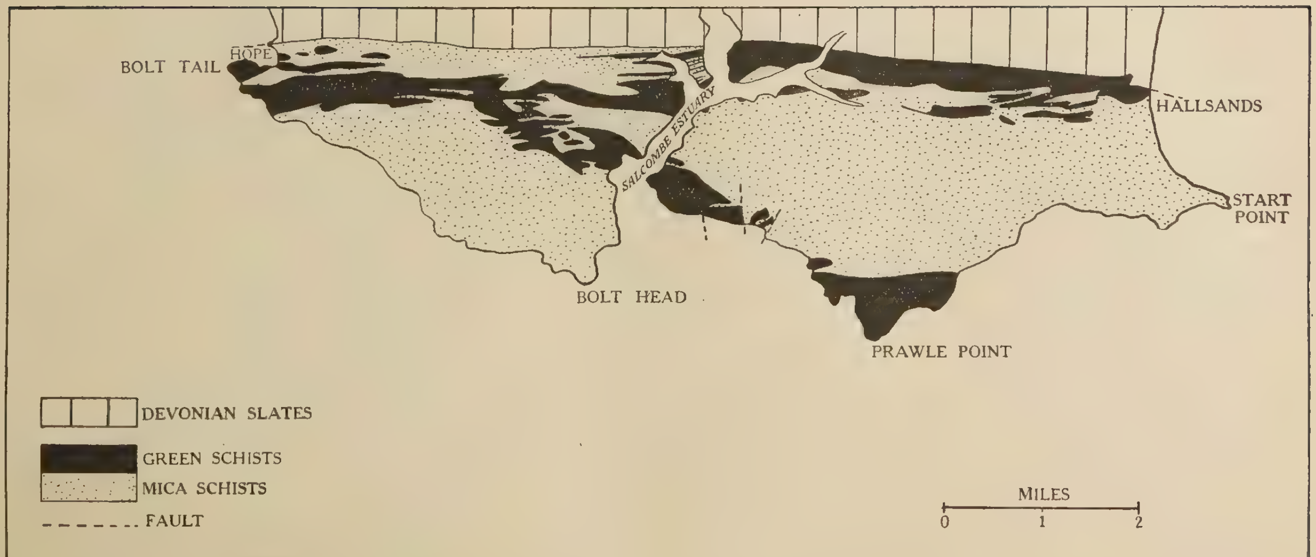
Two main groups of rocks are recognized as constituting the Start Point area: (*a*) mica-schists, and (*b*) Green Schists.

These rocks have a predominant east-and-west strike, and are highly folded. From an examination of the coastal sections, Prof. Bonney (who examined these rocks in 1884) was led to the conclusion that the mica-schists formed a distinct stratigraphic unit lying above the Green Schists. He was of opinion that the Green Schists were basic rocks of igneous origin, but nowhere has he stated definitely whether they were to be regarded as predominantly of tufaceous character, or as lavas or intrusions. On the other hand, W. A. E. Ussher, after mapping the area on the 6-inch scale, reached the conclusion that the mica-schists lay as a group below the Green Schists, forming a core to anticlinal structure in the Green Schists on the eastern side of the Salcombe estuary; but, in the area on the west, the coalescence of the two main bands of

[1] A. R. Hunt, Geol. Mag. 1892, pp. 341–48.

[2] 'The Geology of the Country around Kingsbridge & Salcombe (Explanation of Sheets 355 & 356)' Mem. Geol. Surv.

Geological sketch-map of the Start area.



[The map is oriented north and south.]

Green Schists formed a syncline from their union near Malborough to the Bolt Tail. He considered that

'the Green Schists may unhesitatingly be regarded as an altered series of basic igneous rocks allied to the diabases in composition, and possibly consisting in part of altered tuffs' (*op. cit.* p. 37).

I am of opinion that an adequate explanation of the structure and stratigraphy of this district can only be obtained by recognizing both an upper and a lower group of mica-schists.

Across the strike from their boundary with undoubted Devonian rocks the Start rocks have a width of outcrop attaining a maximum of 3 miles to Prawle Point, and approximately $2\frac{1}{2}$ miles to Bolt Head, the southernmost headland of the western area. Along the strike, and approximately coinciding with the structural axis of the district, they stretch from Bolt Tail to Start Point, the easternmost promontory—a distance of nearly $10\frac{1}{2}$ miles.

For purposes of description, the district may be divided into two areas, the one covering the rocks developed east of the Salcombe estuary, and the other the region stretching from Salcombe to Bolt Tail and the village of Hope.

It is clear from Ussher's mapping that a single major band of Green Schist is developed, which, on account of folding, is split up into two bands, one forming the southern coast of the eastern area, while its northern branch runs in proximity to the southern outcrops of the definitely determined Devonian slates and phyllites.

The following succession is represented in ascending sequence:—

(*a*) Start Mica-Schists.
(*b*) Green Schists.
(*c*) Bolt Mica-Schists,

Area East of the Salcombe Estuary.

East of the Salcombe estuary the Green Schists form two distinct and separate bands, the southern striking eastwards to Prawle Point, and the northern band being developed along the Southpool creek, and at Scoble Point, striking eastwards to the village of Hall Sands.

Investigation of the Green Schists shows that they are to be regarded in large part as dynamically metamorphosed lava-flows—possibly associated with sill intrusions—and beds of composite origin, basic ashes containing the detrital material of normal sediments. The evidence upon which this conclusion rests will be given in the petrographical section of this paper. Ussher's mapping makes it clear that the Green Schists form an excellent datum-line for the elucidation of the structure of the district.

There is every reason to believe that east of the Salcombe estuary the disposition of the rocks is anticlinorial, the mica- and quartz-mica-schists at Portlemouth and Start Point forming the core of the anticlinorium, and the Green Schists resting upon them.

There can be no doubt that the mica-schists and Green Schists

form an intimately related group of rocks: for, in the upper portions of the mica-schists and in the lower bands of the Green Schists, there are intercalations of Green Schists and mica-schists respectively.

One of the best sections for studying the relations of the Green Schists and the mica-schists in this area is the coast-section south of Biddle-Head Point. At Sunny Cove there are evidences of interbanding of mica-schist with the Green Schists, and in the main mass of the Green Schists at this place the dip is 33° south-westwards, overlying the mica-schists on the north. This south-westward to southward dip is continued along the coast, becoming less steep, until at Limebury Point the beds show evidence of rolling, and contain narrow bands of mica-schist and chlorite-mica-schist.

The continuity of the Green-Schist outcrop along the southern coast is broken at Rickham Sands, where faulting has brought into contact the mica-schists and the Green Schists. This fault, as Ussher mapped it, is a dip-fault which can be traced inland to Rickham Farm. A second fault is developed at the eastern end of Seacombe Sands, and from that point to Moor Sands the coast is formed of mica-schists.

The northern boundary of the great mass of the Prawle Green Schists is exposed in Moor Sands on the west, and at Horseley Cove on the east. Inland the boundary-line is for its greater length obscured, its approximate position being in cultivated fields.

At Moor Sands the junction-beds are highly inclined, but the superposition of the Green Schists is maintained. Between this point and Prawle Point the high inclination obtains, until at the signal-station the Green Schists dip at 40° to 45° in a direction slightly west of north.

In the eastern coast-section at Horseley Cove, the beach-reefs display low dips and undulations, finally passing southwards into a northward dip at Langerstone Point, where there are numerous intercalated sedimentary bands exposed on the shore. It is, therefore, probable that, in the Prawle mass of the Green Schists, a compressed synclinal structure is developed.

Igneous bands are developed in the mica-schists north of Horseley Cove, and narrow bands of basic ashes are present in the mica-schists below the Start Point Lighthouse.

The first evidence of the Green Schists forming the northern band of the anticlinorial fold along the Salcombe estuary is furnished by a narrow band dipping northwards close to the Portlemouth Ferry-steps, and the southern outcrop of the northern Green-Schist band is revealed at various points along the southern shore of Southpool Creek. A great development of the Green Schists, with intercalations of mica-schist, follows north (with a dominant northward dip) to the junction with undoubted Devonian rocks in the inlet almost opposite Tosnos Point. The Green Schists are again exposed in Waterhead Creek, and on both sides of the Southpool Creek near Gullet Farm.

On the eastern coast the cliffs at Hall Sands, south of the Bickerton Valley, consist of gnarled and contorted mica-schists overlain by a narrow band of Green Schists dipping northwards. These Green Schists are exposed with the same disposition in greater mass in a quarry west of Hall Sands.

The cliffs at Green Straight are regarded as Devonian rather than as altered members of the Green Schists, and the actual junction at the coast seems to be hidden in the valley itself.

Area West of the Salcombe Estuary.

In the area east of the Salcombe estuary, only one definite group of mica-schists has been recognized: the Start Schists, which underlie the anticlinorial limbs of the Green Schists of the southern coast and of Southpool Creek; but in the western area the structural relations point clearly to a twofold division of the mica-schists. As we proceed westwards, the two bands of Green Schists of the eastern area are seen rapidly to converge into a single folded mass west of Salcombe. As mentioned above, Ussher was of opinion that in the Hope-Malborough section the Green-Schist mass formed a syncline. On this interpretation, the mass of mica-schists lying south of the united Green-Schist band is constituted by Start Schists; but the evidence for this interpretation is nowhere clear.

An examination of the excellently exposed coast-section from Ilbertstow Point to Bolt Head shows that the anticlinorial structure is still preserved, and that there is no evidence proving that the southern band of the Green Schists from Fort Charles to South Sands is an overturned syncline or isocline.

The mica-schists form the core of the anticlinorial outcrop along the Salcombe estuary from Fort Charles, where a fault is well displayed bringing mica-schists against Green Schists along the strike, to a point immediately below the Marine Hotel, at which point the northern limb of the Green Schist is developed.

Minor intercalated bands of Green Schist can be seen in the mica-schists in the shore-section below Woodville.

The lower mica-schists continue westwards in a wedge-shaped outcrop to a point south-east of the village of Malborough, where the northern and the southern band coalesce, and this single major band continues westwards to Bolt Tail.

It is unfortunate that, in this inland tract, exposures of the rocks are few, and the detailed outcrops of the individual beds cannot be accurately mapped, wherefore the boundaries of the Green Schists shown on Ussher's map cannot be always guaranteed. The major band of Green Schist, as we proceed westwards from Malborough, swings slightly round to the south.

In the section exposed at Bolt Tail, the Green Schists are highly inclined. Their junction with the mica-schists of the Bolt mass at Greystone Ledge shows the junction to dip at a high angle northwards, and this high dip is the prevailing dip from that point to Bolt Tail itself.

Ussher's interpretation of the synclinal structure in the Green Schists of this area appears to be dependent on the section which he figures in the frontispiece of his memoir: namely, the section between Outer and Inner Hope. This, however, cannot be used to support the theory of synclinal structure in the main mass of the Green Schists which lie south of the section. I am of opinion that the features displayed in this section are more probably explained by representing the major band of the Green Schists extending from Malborough to Bolt Tail as constituting the core of the anticlinorium formed by the coalescence of the two bands of Green Schist, which (in the Bolt Tail area) have been overturned southwards, giving the predominant northward dip seen in the section from Greystone Ledge to Bolt Tail.

In the sections exposed between Bolt Tail and Whitechurch, especially near Red Rot Cove, there are several thrusts which can be seen from points near the water's edge. These thrusts have a northward inclination, and are probably connected with the overfolding of the Green Schists.

On this interpretation, the mica-schists lying north of the Malborough zone represent the upper mica-schists which abut against Devonian rocks on the north. As Ussher noted, the Green Schists of the northern band give some indication of dying out in a north-westerly direction, and it is probable that the interdigitation of mica-schist represented the incoming of those more normal sedimentary conditions which have given rise to the upper beds of mica-schist that are stratigraphically on the same horizon as the Bolt mica-schists.

The structure of the Start District may, then, be shortly stated as an anticlinorium with an axis pitching westwards; the Green Schists form one major horizon resting on a lower group of mica-schists—those of Portlemouth and Start—, and overlain by the mass of mica-schists of Bolt Head: the latter being represented in the mica-schists lying north of the single band at Malborough. From Malborough to Bolt Tail the summit of the anticlinorium is traversed in Green Schists, the beds being closely compressed, and forming an overfolded sequence in the coast-section at Bolt Tail.

III. The Mica- and Quartz-Mica-Schists.

(*a*) Mica-Schists of the Start-Portlemouth Area.

These rocks are the oldest sediments recognized in the area. They form a very uniform group, so constant in mineralogical and petrographical character that no definite band can be singled out as a datum-line for recognition of structure within the group. Schistosity is usually well developed, and intricate folding and gnarling on a minute scale is often seen.

While there are patches free from quartz-veining, the greater part of the area of these rocks exposed shows that the beds have

been penetrated by quartz solutions in the direction of the major planes of schistosity. Not only quartz-veins, however, but quartz-albite-veins are frequent, some of these reaching a foot in thickness. Albite, often pink-weathered, may predominate almost to the exclusion of quartz. In the Start Schists this veining is well developed in the coast-sections between Mill Bay and Biddlehead Point, near Dekkler's Point east of Seacombe Sands, and along the coast-sections at Peartree Point, near Start Lighthouse.

The intimate relation of these rocks with the associated Green Schists is shown by the interbanding near the junction with the latter, and by isolated lenticles of Green Schists enclosed within the main mass of mica-schists. Good examples are afforded at points north of Horseley Cove, below the lighthouse at Start Point, and the bands near the Ferry at Portlemouth, and below Woodville on the opposite shore of the estuary.

(*b*) Mica-Schists of the Bolt Area.

The mica- and quartz-mica-schists of this area are separated from the group already described by the band of Green Schists stratigraphically interposed. There are no lithological distinctions between the two groups such as can be recognized.

Although the Bolt area is not so continuously accessible as the lower group of mica-schists, yet it is worthy of remark that, in the southern mass extending from Bolt Head to their western limit, no signs of vulcanicity can be observed. The mica-schists are, in the same manner as in the Start group, intimately penetrated by quartz- and quartz-albite-veins.

There is a dominant southward dip of the schistosity in the section exposed from South Sands to Bolt Head; but the absence of any well-defined lithological horizon prevents detailed determination of structure within the group.

(*c*) Petrography.

Petrographically, the Start and Bolt schists are indistinguishable; and in the following petrographic description both groups are included. The mineralogy of these argillaceous sediments is comparatively simple. The principal constituents are quartz and the white mica muscovite, but chlorite and albite may be important members. Accessorily developed are titanite, tourmaline, iron-ores, epidote, zircon, rutile, apatite, and ilmenite.

Quartz is developed in areas separating bands of muscovite and chlorite. These grains are often distinctly elongated, and are intergrown with a typical sutured texture, sometimes showing undulose extinction. There is thus clear evidence that recrystallization *in situ* is involved.

Muscovite and chlorite form layers in which these minerals are in intimate association. The chlorite is often noticeably pleochroic, in green to pale yellow-green tints, and may show

abnormal interference-tints (indigo blue to brown). There is no reason to believe that any of this chlorite is secondarily derived from metamorphic biotite *in situ*. The stage of typical biotite development in the argillaceous rocks of this area has not been reached.

Usually albite is sparingly developed in these rocks, associated with quartz, and distinguished by its cleavage and refraction, and biaxial optically positive character. When it is present in abundance, there is clear evidence (from other considerations) that a rock of composite origin is involved.

Albite figures in a remarkable mass of mica-schist in the Bolt area near Starehole Bay, and Bolt Head. At this point the mica-schist is found to contain knots of a black well-cleaved mineral, forming porphyroblasts in a quartz-chlorite-muscovite groundmass. Thin slices of these rocks show that these porphyroblasts are albite, the blackness being due to carbonaceous inclusions.[1] These carbonaceous inclusions form zonal bands in the albite, and are associated with minute highly-refringent prisms of rutile. The rutile is often abundant in the porphyroblasts themselves, and good examples of the sagenite web occur. Albite-twinning is developed in broad but irregular bands. The zonary structure induced by the carbonaceous swarms is not infrequently irregular, sinuous, and contorted, and the carbonaceous particles are also found in the muscovite-chlorite layers.

The remaining minerals of the mica-schists are developed as accessories. Titanite in minute wedge-shaped grains is not uncommon, and a like remark applies to tourmaline, usually showing pleochroism in brownish-green to brown tints. The iron-ores include magnetite, often showing alteration to hæmatite, secondary limonite, and pyrites. Porphyroblasts of ilmenite, now largely leucoxenized, occur in a quartz-mica-schist from Start Cove. Zircon may occur with pleochroic haloes in chlorite.

In the normal mica-schists garnet is a rare constituent; but its presence is noted in a quartz-mica-schist from Seacombe Sands, where it is developed in association with chlorite and muscovite in idioblastic dodecahedra. This mineral is, however, not uncommon in those schists of composite origin which are described below.

IV. The Green Schists.

(*a*) General Description.

The distribution and the stratigraphical position of these highly interesting rocks have been dealt with in a previous section of this paper. The lithological and petrographic characters of the rocks remain to be touched upon.

They are characterized by an almost universal green colour, showing gradations from a yellowish green to a strong deep green. At their junctions this green coloration is often replaced by red and brown tints. This is clearly due to the presence of films of

[1] I believe this mineral to be that mentioned in Q. J. G. S. vol. xliii (1887) p. 724, and there figured (fig. 2) and identified as kyanite.

hydrated iron oxide, but the mineralogical constitution is not affected. These rocks are, as a rule, distinctly schistose, though more massive types are not uncommon. They show, in many cases, alternations of colour from yellowish green to deep green parallel to the schistosity, and this in some respects simulates a bedded structure. In thin sections this structure may be revealed by successive bands showing variable mineralogical composition, such as narrow layers rich in albite adjoining layers in which chlorite or hornblende is more abundant. On weathered surfaces this pseudostratal structure is accentuated by the protrusion of small crystals of the more resistant albite. Furthermore, the Green Schists have not infrequently been penetrated along the planes of schistosity by quartz solutions, but on a scale far from commensurate with that developed in the neighbouring mica-schists. The resistant weathering of these narrow films of quartz tends further to accentuate this structure.

Many of the schists are characterized by a pitted or cavernous structure, and these hollows can be shown to represent weathered-out grains of calcite, or quartz of the quartz-veining.

Among other macroscopic structures developed in the Green Schists, we may note the presence of nodular masses largely consisting of yellow-green epidote. Such masses, varying in size from half an inch to 6 inches, occur in the Green Schists in various parts of their exposure. Some of the best examples can be studied in the coast-sections between the Bull and Limebury Point, at the southern end of the Salcombe estuary, and also in the Prawle mass of the Green Schists at Hamstone Cove, and the neighbourhood. It is in every way probable that these represent amygdales, and are the metamorphosed equivalents of infilled vesicles in an original volcanic rock (see p. 187).

I have already referred to the presence of quartz-veinlets in the Green Schists. These have the same origin as those developed in the associated mica-schists. In the latter rocks, however, they are much more abundant than in the Green Schists. This contrast can nowhere be better exemplified than in the narrow bands of mica-schist associated with the Green Schists at their lower and upper junctions. There can be no doubt that this contrast is due to the fact that the invading solutions have selectively penetrated the mica-schists, on account of their more perfectly developed schistosity. Quartz-albite-veins must be quite exceptional in the Green Schists themselves.

Petrographically, the Green Schists can be divided into two distinct types:—(i) chlorite-epidote-albite-schists; and (ii) hornblende-epidote-albite-schists. There are gradations between these types, in which chlorite and hornblende are almost equally developed. Nor can we separate these two dominant types with regard to any zonal distribution, for both are to be recognized in all the areas where the Green Schists are developed. Nevertheless, there is good reason to believe that these rocks represent different grades of dynamic metamorphism of one and the same rock-type.

(b) Petrography.

(i) Chlorite-Epidote-Albite-Schists.

The constituent minerals of these rocks are chlorite, epidote and clinozoisite, albite, titanite; and (accessorily) calcite, hornblende, quartz, also in some examples a few flakes of white mica. The petrographical character of this group of the Green Schists can be exemplified by the description of a Green Schist from Seacombe Sands, Prawle coast. Macroscopically, this is a silky, grey-green, distinctly schistose rock, showing white grains of albite. Under the microscope the constituents seen to be present are chlorite, epidote, albite, titanite, hornblende, and magnetite.

The chlorite forms plates with which the fibres of amphibole are intergrown, and yielding a green to yellow-green pleochroism. Sections examined show almost uniaxiality and positive optical character, with low double refraction.

The epidote is a ferriferous type giving third-order carmine tints, and a strong pleochroism in yellow-green tints. It is optically negative, the birefringence having a value of 0·038 corresponding to a ferric-oxide content of 14 to 16 per cent.

The felspar is an albite with refringence less than Canada balsam, and extinction on 010 of 19°. It is optically positive. Twinning is rare, and cleavage is often absent. The most common inclusions in the albite are grains of epidote and fibres of amphibole.

Titanite occurs in rounded grains of high relief, associated with epidote and chlorite.

The amphibole is present in long needles with cross-parting, associated with chlorite or enclosed in albite. The colour is bluish green to almost colourless, and the maximum extinction from the prism axis is 20°.

A very small amount of quartz is interstitially found among the albite grains, characterized by its higher refringence, and proved by optic uniaxiality. A single grain of apatite is present.

The crystals of chlorite and amphibole are oriented in parallel enclosing grains of epidote, and such bands may be separated by areas of albite.

This Green Schist was selected as a type-rock for analysis. It is free from calcite, and was so selected, as it is not clear how far the calcite in these rocks represents migration of material. The results of this analysis are set forth in the accompanying table (p. 183). Quoted with it are the analyses of a number of comparable basalts, Prof. R. A. Daly's average for all basalts, and two analyses of dynamically metamorphosed rocks which are mineralogically similar.

The agreement between these analyses confirms the essentially igneous character of the rocks.

	Epidote-Chlorite-Albite-Schist. I.	*Basalt.* II.	*Basalt.* III.	*Epidote-Chlorite-Schist.* IV.	*Epidote-Chlorite-Schist.* V.	*Average of all Basalts.* VI.
SiO_2	48·60	49·90	48·35	47·85	47·88	49·06
Al_2O_3	15·40	15·79	15·47	16·51	15·41	15·70
Fe_2O_3	4·07	4·52	4·80	4·16	4·91	5·38
FeO	7·47	6·25	7·58	7·43	5·69	6·37
MgO	7·60	5·77	8·15	6·24	6·87	6·17
CaO	8·34	9·12	8·81	7·00	10·71	8·95
Na_2O	3·18	3·24	3·09	3·20	3·67	3·11
K_2O	0·50	0·89	0·95	0·82	0·49	1·52
H_2O +	3·31	1·36	0·73	4·00	2·74	} 1·62
H_2O −	0·38	1·28	0·28	0·21	0·04	}
TiO_2	1·77	1·98	1·33	2·28	1·67	1·36
P_2O_5	tr.	0·43	0·33	0·35	n. d.	0·45
MnO	n. d.	0·12	0·21	0·24	0·18	0·31
Accessories	—	—	0·18	0·12	—	—
Totals	100·62	100·65	100·26	100·41	100·26	100·00
	Seacombe Sands, Prawle coast (South Devon).	Chinghee Creek, Telemon Parish (Queensland).	San Rafael, Colfax County (New Mexico).	Montezuma, Mitchell County (North Carolina).	Oberstafel (Switzerland).	
Specific gravity	$\frac{14\frac{1}{2}°}{4°}$ 2·936	2·76	—	—	3·00	—

II. H. C. Richards, Proc. Roy. Soc. Queensland, vol. xxvii (1916) p. 177.
III. F. W. Clarke, Bull. U.S. Geol. Surv. No. 695 (1920) p. 452.
IV. *Id. ibid.* No. 419 (1910) p. 37.
V. H. P. Roothaan, Jahresber. Naturforsch. Gesellsch. Graubünd. vol. lix (1919) p. 63.
VI. R. A. Daly, 'Igneous Rocks & their Origin' 1914, p. 27.

The norm of this rock is:—

	Per cent.		Per cent.
Orthoclase	2·78	Hypersthene	13·92
Albite	27·25	Olivine	4·62
Anorthite	26·70	Magnetite	6·03
Diopside	12·26	Ilmenite	3·50

and the mode, as in part determined:—

	Per cent.		Per cent.
Titanite	4·5	Chlorite	65·5
Albite	30·0	Epidote	
		Hornblende	

Green Schists showing porphyroblasts of albite in a chlorite-epidote ground-mass are not uncommon. On weathered faces the albite-crystals stand out from the rock, imparting to it a knotted appearance. A good example of a rock of this type from Leek Cove was studied. From the type already described this rock differs mineralogically in the presence of a considerable amount of white mica, and its association with narrow bands of undoubted sediment leads to the conclusion that the rock is a metamorphosed basic ash.

The constituents are chlorite, epidote, albite, titanite, blue-green fibres of amphibole especially associated with chlorite, muscovite, and magnetite giving place to hæmatite. Some bands of this rock are very rich in muscovite associated with chlorite. Quartz is absent.

The porphyroblasts of albite range in size up to 1·5 mm., are occasionally twinned, and cleavages are usually well developed. They commonly show a poikiloblastic texture, due to the presence of fibres of amphibole and elongated crystals of a ferriferous epidote. These are characteristically arranged in parallel, but are not necessarily parallel to the longer axes of the porphyroblasts of albite. Except for the inclusions above noted, the albite-grains are water-clear. A rock of this character, except that muscovite is absent, is described from Inner Hope by Sir Jethro Teall in Ussher's memoir.[1]

The rocks so far described have been completely free from a carbonate mineral. Usually, however, this mineral (calcite) is common among many of the Green Schists of this type. The calcite in some cases may rank as an important constituent, and there is every reason to believe that it has crystallized as such during the metamorphism of the rocks. It is intimately intergrown with albite, and shows multiple twinning of the usual type. Chlorite is the common inclusion, but enclosures are not abundant. In accordance with its position in the crystalloblastic series, the calcite is moulded on to the more idioblastic albite. In the true

[1] 'The Geology of the Country around Kingsbridge' Mem. Geol. Surv. 1904, p. 61.

Green Schists, quartz is never a prominent constituent, but is usually present in minor amount associated with albite-grains.

The presence of abundant quartz and muscovite is characteristic of the composite rocks dealt with below.

Biotite enters as a subordinate constituent of a Green Schist south of Moor Sands, west of Prawle Point. This is the more noteworthy, on account of the remarkable rarity of this mineral in the rocks of the immediate neighbourhood of Start Point. It is developed in flakes associated with chlorite. Some muscovite is similarly associated. The pleochroism of this mica is pale yellow to dark brownish-green, and it is practically uniaxial. It is in this rock that nodular masses of epidote, calcite, and chlorite are developed, the nature of which will be considered on a later page.

(ii) Hornblende-Epidote-Albite-Schists.

By increase in the amount of hornblende in these rocks, and concomitantly a decrease in the quantitative proportion of chlorite, the Green Schists pass into the second well-defined type of the hornblende-epidote-albite-schists. There is no doubt that these rocks represent an increasing grade of metamorphism of one and the same rock-type. They can be recognized from all parts of the area where the Green Schists are exposed.

The petrographic character of this type of Green Schists can be indicated by the description of a rock which occurs at Prawle Point close to the signal-station. Macroscopically, it is a grey-green, not markedly schistose rock, showing porphyroblasts of a dark-green cleavable mineral projecting on weathered surfaces. Under the microscope the constituents seen to be present are hornblende, epidote, albite, titanite, and chlorite. The principal constituent is a colourless to grey-green hornblende, present as porphyroblasts measuring up to 1·5 mm. in length. It is only weakly pleochroic in pale green tints. Hornblende is also developed as cross-fractured fibres, as in the chlorite-epidote-schists. The maximum extinction-angle is 22°, and the birefringence =·022. The periphery of these porphyroblasts is often enclosed by aggregates of epidote-granules, with which titanite-granules are mingled. The optical character of the hornblende is negative.

Epidote occurs in subidioblastic grains of quite small dimensions. This is a less ferriferous type than that represented in the chlorite-epidote-schist previously described. The birefringence =·028, and there may be zonal structure developed. In such cases the shell is more ferriferous than the core.

Albite rarely forms porphyroblasts in any of these rocks, but usually is interstitially developed. It may be a less sodic type than the albite of the chlorite-epidote-schists. The refractive index is only slightly lower than that of Canada balsam. Cleavage is rarely developed, and the same remark applies to twinning. It is clear that some of this felspar is as calcic as acid oligoclase, for some of the slides show grains with the refringence of Canada balsam, and give a negative optic figure.

Titanite is usually present in spindle-shaped grains, or is xenoblastic.

The chlorite is an accessory constituent, having the properties of the chlorite of the chlorite-epidote-schists. It is in intimate association with the hornblende. The texture of the rock is distinctly crystalloblastic.

This rock was selected for analysis as typical of the second group of the Green Schists. In the accompanying table are recorded analyses of both igneous and metamorphic rocks of comparable composition. It will be clear from this table that the rock is essentially of basaltic composition, similar to the Tertiary basalts of the Western Isles of Scotland, and among metamorphic rocks we find its analogues in hornblende-schists from the Lizard and Norway, and in a greenstone-schist from Rainy Lake (Canada).

	VII.	VIII.	IX.	X.	XI.	XII.
SiO_2	49·32	48·25	46·61	47·11	48·64	46·28
Al_2O_3	14·82	14·06	15·22	19·75	14·99	14·24
Fe_2O_3	3·08	3·39	3·49	2·30	3·42	3·93
FeO	7·27	9·38	7·71	4·59	7·76	11·62
MgO	7·94	6·60	8·66	7·73	7·76	7·40
CaO	11·25	10·82	10·08	11·67	9·60	11·28
Na_2O	2·54	2·54	2·43	2·80	3·52	2·48
K_2O	0·32	0·61	0·67	0·80	0·52	0·81
H_2O +	2·26	2·08	2·07	1·72	1·25	0·28
H_2O −	0·13	0·56	1·10	0·07	0·10	0·05
TiO_2	1·55	2·47	1·81	0·67	1·90	1·70
P_2O_5	—	n. d.	0·10	0·10	0·16	0·15
MnO	n. d.	—	0·13	0·08	0·30	0·02
Accessories	n. d.	—	—	0·02	0·29	0·15
Totals	100·4	100·76	100·08	99·41	100·21	100·39
Specific gravity	$\frac{17°}{4°}$ 3·010	$\frac{14°}{4°}$ 3·003	2·87	$\frac{20°}{4°}$ 3·060	—	—

VII. Hornblende-epidote-albite-schist, Signal-Station, Prawle Point.

VIII. Tachylyte of basic andesite, Kildonan, Eigg. Min. Mag. vol. xix (1922) p. 288.

IX. Olivine-basalt, Drynoch (Skye). A. Harker, 'Tertiary Igneous Rocks of Skye' Mem. Geol. Surv. 1904, p. 31.

X. Amphibolite-schist (metamorphosed lava), Naversnes, Finnö (Stavanger). V. M. Goldschmidt, Vidensk. Selsk. Skrifter, No. 10 (1920) p. 12.

XI. Hornblende-schist, the Lizard. E. G. Radley, in J. S. Flett & J. B. Hill, Mem. Geol. Surv. 1912, p. 48.

XII. Greenstone-schist islet in Rocky Islet Bay. A. C. Lawson, Mem. Geol. Surv. Canada, 1913, No. 40, p. 50.

The norm of this rock is:—

	Per cent.		Per cent.
Orthoclase	1·7	Hypersthene	16·3
Albite	21·5	Olivine	0·8
Anorthite	28·1	Magnetite	4·4
Diopside	22·4	Ilmenite	2·9

while the calculated mode gives:—

	Per cent.		Per cent.
Hornblende	47·5	Chlorite	2·0
Epidote	22·5	Titanite	3·7
Albite	23·7		

Analysis VII shows that the hornblende must be of an aluminous type. The approximate composition, as calculated from the analysis, is CaO 11 per cent., MgO 16, FeO 15, Al_2O_3 9, and SiO_2 48. A comparable hornblende is that of the hornblende-dacite from San Pedro, Sierra del Cabo, Cabo de Gata (Spain): see Whitman Cross & others, 'Quantitative Classification of Igneous Rocks' 1903, Table XIII *c*.

When this analysis (VII) is compared with that of the chlorite-epidote-albite-schist, it will be seen that the main distinction is the higher lime content and lower soda content of the former. By advance in metamorphism, chlorite has given place to hornblende, partly at the expense of epidote and probably also by reaction with calcite. With this increasing metamorphism the character of the plagioclase slowly changes. A more calcic type of felspar is stable under higher-grade metamorphic conditions.

As has been noted above, rocks of this type are widely distributed in the Start Green Schists, but no zonal areas can be differentiated. Other notable localities for hornblende-schists are Bolt Tail, and Inner Hope, Southpool Creek, and Spirit of the Ocean Cove, near Start Point, where an isolated mass of Green Schist is found among the mica-schists. This latter rock has been described by Dr. A. Harker, and his description is quoted by W. A. E. Ussher in the Geological Survey Memoir, p. 51. The mineralogy of this rock is essentially similar to that of the Prawle Point rock. Epidote is more abundant, and the distribution of the albite is somewhat different. In this rock it forms granular aggregates of lenticular shape, and between the lenticles are developed amphibole, epidote, and titanite, with chlorite. Calcite is also present. It is possible that this rock represents a sill-intrusion in the Start mica-schists.

In other members of the hornblende-epidote-schists, such as, for example, a band at Seacombe Sands, the hornblende does not form stout porphyroblasts, but is wholly developed in long colourless to pale-green fibres with marked cross-parting, associated with epidote and less abundant chlorite, and separating lenticular areas of albite. With this development the schistose texture is strongly marked.

(iii) Nodular Masses in the Green Schists.

At various points in the Green-Schist outcrops east of the Salcombe estuary, notably in the vicinity of Limebury Point and Hamstone Cove, yellow to yellow-green nodules are found in the Green Schists. Owing to their more resistant weathering, these masses stand out from the face of the rock. The nodules range in greatest diameter from 6 inches to less than 1 inch, but measure

commonly less than 2 inches across. Epidote forms the major constituent of all these knots, and with it are associated chlorite, hornblende, calcite, and albite.

Some of the knots are made up essentially of epidote and hornblende. The knots examined from Hamstone Cove consist of finely granular epidote, intergrown with albite, and accessorily chlorite, hornblende, calcite, muscovite, and quartz. Some of the hornblende prisms are in process of being replaced by biotite-flakes. A few of the knots of Limebury Point are essentially made up of ferriferous epidote. The grains of epidote are variable in size, even within the one nodule, the periphery often being more coarsely granular than the interior.

No zonal arrangement of minerals can be made out, however, in any of these nodules. The distribution of epidote in the Green-Schist masses of the Start shows no analogy with the remarkable associations of this mineral in the Landewednack hornblende-schists of the Lizard. In the latter locality it would appear that the original igneous rocks had suffered much decomposition by weathering, with migration of material, giving rise to calcite and other products, which on metamorphism have yielded banded types of hornblende-epidote-schist.

Such types are wholly absent from the Green Schists of the Start area. It appears more probable that the nodules of these Green Schists represent amygdales in an original volcanic rock, which in metamorphism have yielded epidote as the prime constituent. Amygdales of this character are recognized in other Green-Schist areas, and it will suffice to note that in the Lake Superior region such examples are provided. In the Marquette greenstone, G. H. Williams[1] records small amygdales filled with brightly polarizing epidote, often associated with calcite.

Nowhere in the Start area can any evidence of ellipsoidal or pillow-structure be observed, and, considering the very marked dynamic metamorphism to which these rocks have been subjected, the absence of such structures calls for no further comment.

V. Schists of Composite Origin.

Under this heading are included those rocks which betray, either by their aspect in the field, or by their mineralogical composition, their character as neither normal sediments nor true igneous rocks. Such rocks are often abundantly developed in association with the true Green Schists, especially at the junctions of these rocks with the associated mica-schists. There is every reason to believe that these rocks are tufaceous in origin, or are basic ashes.

They form a natural link between the normal sedimentary mica-schists on the one hand, and the essentially igneous derived Green Schists, on the other. Such types appear to have been described under the title of 'the micaceo-chloritic series' by Miss C. A. Raisin. Apart from the light that they throw on the original

[1] Bull. U.S. Geol. Surv. No. 62 (1890) p. 174.

nature of the Start group of rocks, they are not without interest from a petrographical point of view, more especially in regard to the mineralogical changes associated with progressive metamorphism.

These rocks occur characteristically at the upper and lower horizons of the Green-Schist band. They are particularly well developed in association with the northern band, as at Ilbertstow Point and Scoble Point. Within the Green-Schist band they are abundant at Langerstone Point, and near Limebury Point and Leek Cove, as also at other localities.

As a group they contain the following minerals:—chlorite, epidote, albite, calcite, sphene, quartz, muscovite, rutile, iron-ores, garnet, and hornblende. Apart from the abundance of muscovite and quartz in them, and the presence of rutile and garnet, these rocks are differentiated from the Green Schists by their very variable composition. This variability of composition is not infrequently shown within single sections cut for examination under the microscope.

Petrographically, two types can be distinguished:—

(*a*) Quartz-muscovite-chlorite-albite-schists.
(*b*) Quartz-muscovite-chlorite-albite-garnet-schists.

(*a*) The properties of the first type can be gleaned from a description of a rock occurring as a band among the Green Schists at Limebury Point. Macroscopically, it has the habit and appearance of the normal mica-schists, glistening folia of muscovite and chlorite being separated by quartzose layers.

Under the microscope, the muscovite and chlorite are seen to be intimately intergrown, the latter appearing in pale-green pleochroic tints with low interference-colours, an abnormal brown tint being not uncommon. These layers of muscovite and chlorite have a highly sinuous development. Between them lie quartz and albite in interlocking grains, the quartz frequently showing undulose extinction.

The accessory minerals are titanite, epidote, and iron-ore (now hæmatite and limonite). Yellow prisms of rutile are occasionally abundant.

(*b*) In the next type, garnet appears. The best development of these rocks occurs among the Green Schists in the Prawle mass at Langerstone Point. The garnet is present in well-shaped dodecahedra, reaching 1/16 inch in diameter. In other respects these rocks do not differ materially from the type already mentioned. They show considerable variation in their quartz content. Sphene and epidote are often abundantly developed in association with the muscovite-chlorite intergrowths. Apatite is a common accessory. The idioblasts of garnet reach 1·5 mm. in diameter, showing quadrate or hexagonal outlines, and are pinkish in colour. They are also isotropic. Poikiloblastically epidote or clinozoisite, and less commonly sphene and quartz are found within its borders.

The refractive index of the garnet (as measured in methylene iodide saturated with sulphur) exceeds 1·78, and the specific gravity of carefully selected crystals is 3·94. In none of these rocks do the garnets exhibit any signs of incipient alteration. Hornblende is a rare constituent of the composite rocks, and (if present) is characteristically developed in those areas that are free from white mica. Biotite is the most notable absentee, and there is no reason to believe that it has ever figured as a constituent of these rocks.

It was of interest to determine whether the garnet of these rocks was a normal almandine, or if other bases than ferrous oxide were present in notable amount. Qualitative analysis showed a high content of ferrous oxide. Manganese was determined colorimetrically, and found to constitute 5·5 per cent. as manganous oxide, corresponding to a spessartine content of 12·8 per cent. The ferrous iron content exceeds 20 per cent., and the garnet must therefore be regarded as a spessartine-almandine.

There is reason to believe that the early appearance of garnet in these rocks is connected with the manganese content of this mineral. That point will be considered in § VII of this paper; but we may note at this stage that an early appearance of garnet is conditioned by a similar peculiarity in rocks of the Ardennes,[1] and in metamorphosed phyllites of the Stavanger district of South-Western Norway.[2]

VI. The Metamorphic Boundary.

The literature devoted more especially to the relations existing between the metamorphosed rocks of the Start area and the Devonian rocks lying on the north has been summarized by Sir Jethro Teall in W. A. E. Ussher's Geological Survey memoir. Ussher himself gave an admirable description of the evidence concerning the boundary, but preferred to leave undecided the mutual relations of the two groups of rocks.

The problem resolves itself as follows :—

(i) Absence of a definite boundary, but a progressive metamorphism increasing in intensity southwards.

(ii) A definite boundary (*a*) of unconformity, and (*b*) of dislocation.

Of these solutions the first was supported by, among others, H. B. Holl, A. R. Hunt, and A. Somervail. These writers regarded the evidence as one of progressive metamorphism, and concluded that the Start group of rocks is satisfactorily explained as consisting of Devonian rocks in a higher grade of metamorphism.

On the other hand, Prof. T. G. Bonney and Miss C. A. Raisin have given reason to believe that the Start rocks are separated

[1] A. Renard, 'Les Roches Grenatifères & Amphiboliques de la Région de Bastogne' Bull. Mus. Roy. Hist. Nat. Belg. vol. i (1882) p. 10.

[2] V. M. Goldschmidt, 'Die Injektionsmetamorphose im Stavanger-Gebiete' Vidensk. Selsk. Skrifter, No. 10 (1920) pp. 68–69.

from the undoubted Devonian by an important dislocation. The former, in particular, is emphatic with regard to the prior state of metamorphism of the Start Schists, and has classed these as Archæan.

The evidence which has been adduced for the theory of progressive metamorphism is of a very doubtful character. Holl[1] was of opinion that the southern area represented an area of contact-metamorphism mantling a hidden mass of granite. This view is wholly unwarranted. There is no evidence that thermal metamorphism has played any part in the development of the schists. On the contrary, the mineralogy of these rocks is that characteristic of dynamic metamorphism.

The views of Hunt with regard to analogies in mineral composition between Devonian rocks and members of the Start Schists are scarcely cogent evidence for any correlation of these two groups of sediments.

The hypothesis of a boundary of unconformity can be dismissed, for there is no evidence by which such a view can be sustained.

For the view that a separate boundary of dislocation separates the southern schists from the undoubted Devonian sediments, there is much support. The great development of Green Schists in the Start area can find no parallel in any igneous horizon in the Devonian rocks of the northern area. Wherever continuous exposures are developed between Devonian slates and the Start Schists, the determination of a boundary-line within a few yards is never left in doubt. Ussher, in the memoir already quoted, devoted a chapter to this evidence for a boundary, and the data brought forward are so convincing that there is little to add to his descriptions.

The principal sections which afford indications of the relations of the two groups of rocks are the coastal and estuary exposures, those of Hall Sands, Southpool Creek (particulary the west side), the east and west sides of the Kingsbridge estuary, north of Scoble and Ilbertstow Points, and lastly the section revealed at Hope on the western coast.

The Devonian slates at all these points are highly inclined, with a dominant cleavage-dip northwards, and the bedding near the junction, where it can be ascertained by the presence of siliceous or calcareous bands, has also a strong northward inclination. At the immediate junction where Green Schists are present, they have been converted into 'brown rocks', owing to a secondary development of iron-oxides. This ferruginous development is characteristic of the rocks along the whole length of the boundary-line, and in itself is evidence favouring dislocation.

One of the best sections for studying the relations of the rocks at the boundary is that displayed on the western shore of Southpool Creek, near Gullet Quarry. The evidence of a dislocated

[1] Q. J. G. S. vol. xxiv (1868) pp. 438–39.

junction here is very strong. This junction is seen north of the quarry in the Green Schists. The Devonian slates are altered to brownish iron-stained types, and the junction is marked by an ironstone band hading northwards at a point close to the edge of the quarry plantation.

Ussher saw fit to class the brown rocks north of this point as of Green Schist type; but I am in agreement with Miss Raisin that these are Devonian, for the typical glossy phyllites can be distinguished in them. These brown rocks have a cleavage-dip northwards, whereas south of the junction the Green Schists dip southwards, forming a syncline.

In the section at Hall Sands the actual junction is not exposed, but must lie in the small valley between the cliffs at Greenstraight and the cliffs below the chapel. The cliff at Greenstraight consists of Devonian rocks which have been stained by iron-oxide near the fault, and correspond to the brown rocks in the Southpool-Creek section. These beds dip consistently northwards, and are followed by the normal Devonian slates.

Inland, on the north side of the Bickerton valley, a disused quarry discloses Green Schists, as Somervail first noted. It is clear, as one proceeds eastwards, that the boundary-line is deflected northwards, probably by a transverse fault; but this cannot be made out on the ground, owing to lack of exposures. In the sections north of Scoble and Ilbertstow Points on the Kingsbridge estuary, the junction-line must lie between slates and mica-schists. The rocks affected by ferruginous solutions are here the mica-schists.

The remaining junction-section is that exposed along the shore at Hope village. The junction-rocks here have been intensely affected by the intrusion of quartz-veins. North of the rocky headland well-defined Devonian slates with a northward dipping cleavage crop out on the beach. The junction is exposed in the headland itself: the secondary changes in this case, however, have involved, not only the Devonian strata, but the quartz-mica-schists which form the junction-beds of the southern group. The exact position of the junction cannot be more exactly defined, owing to the enormous amount of infiltrated quartz in the form of veins which has involved both the Devonian rocks and the quartz-mica-schists.

Summing up the evidence yielded by the sections noted above, one may assert that the metamorphic boundary is well defined. On the north are developed well-cleaved glossy slates, and on the south either Green Schists or mica-schists, which are readily distinguishable from the cleaved slates. Wherever sections can be examined, it can be shown that the rocks at the junction are involved to a greater or less extent in a secondary alteration brought about by ferruginous solutions yielding the so-called 'brown rocks.' These brown rocks may include both members of the Start group or the Devonian slates themselves. At Hope the junction-beds are mica-schists, and the same applies to the section on the Kingsbridge estuary.

At Southpool Creek the junction-beds are Green Schists, and the development of an ironstone band marks the fault-plane. The fault-zone at Hope is characterized by an abundant development of quartz-veins and segregations.

The marked distinction in petrographic character of the rocks on either side of the boundary, the persistent development of alteration in the rocks along the boundary, and the structural discontinuity in the Southpool-Creek section, lead inevitably to the conclusion that the boundary-line represents a plane of major dislocation, bringing together rocks of different origin and markedly different grades of metamorphism.

Taking into consideration the known direction of movement of the Armorican folding which has affected the Devonian and Carboniferous rocks of the South of England, we might expect that the boundary of dislocation should show some evidence of a northward overthrust movement corresponding to the northward stresses of this post-Carboniferous movement. The evidence of the boundary, so far as it can be interpreted, does not, however, support this view.

The direction of cleavage-dip of the Devonian slates immediately north of the boundary-line is uniformly northward, and there is no evidence to suggest that the major fault-plane hades in a southerly direction.

VII. Nature of the Metamorphism.

The interpretation of the boundary of the Start Schists with the Devonian rocks lying on the north, as a plane of major dislocation, raises questions of interest in regard to the age of these rocks and their metamorphism. It must be admitted at the outset that these questions, through lack of definite evidence, are not at present capable of complete solution. The same problem, in fact, as that which has confronted investigators of the Lizard area confronts the investigator here. No one has yet discovered any evidence of organic remains among the sedimentary mica-schists of the Start area.

Petrographically, the rocks are allied in some ways to the pre-serpentine rocks of the Lizard: namely, the mica-schists and hornblende-schists into which the plutonic complex of the Lizard is intruded. Mineralogically, the Green Schists bear considerable resemblance to the 'green beds' of the pre-Cambrian of Scotland. It is clear however that this group of rocks was involved in a pre-Devonian epoch of folding, and one during which the essential metamorphic features of these rocks were impressed upon them. In Britain, among Palæozoic rocks, no assemblage is known having their petrographic character. In Western Norway, however, rocks of this type (phyllites, mica-schists, and green schists of Cambrian to Silurian age—particularly Lower and Upper Ordovician) are found, as in the Stavanger district and elsewhere. These rocks have been subject to metamorphism during the Caledonian epoch.

The problem at issue in regard to the Start Schists involves the consideration of them as

(i) Pre-Cambrian or pre-Devonian rocks which have acquired their metamorphic features during the Caledonian movements; or

(ii) Pre-Cambrian rocks which were already metamorphosed prior to the Palæozoic Era.

The petrographic resemblance to the adjacent pre-serpentine rocks of the Lizard suggests that the mica-schists and Green Schists of the Start area and the Old Lizard Head Series (with the associated hornblende-schists) have a common origin.

Dr. J. S. Flett & Mr. J. B. Hill, in considering the question of the age of the Lizard group, and in reference to a possible Ordovician date, state that the north-north-westerly strike of the Lizard schists

'is very strong evidence of their pre-Cambrian age, for neither in Britanny, in South Wales, nor the South-East of Ireland, where extensive areas of these rocks occur, has any reason yet been found to lead us to the belief that the late Silurian, or Caledonian movements produced folds striking in that direction.'[1]

The magnitude and intensity of the folding during the Caledonian epoch do not appear to have been great in the South of England, the regions of acute disturbance lying farther north. The metamorphic effects, as revealed in the Ordovician rocks of Cornwall, where a pre-Devonian folding has been recognized, are (in those areas that are dissociated from thermal metamorphism) of no great magnitude.

We are led to consider that the Start group of rocks should be added to the pre-Cambrian, in which period the main metamorphism was already effected. The trend of the Armorican folding, revealed in the Devonian rocks on the north, corresponds very closely to the west- and west-north-westerly trend of the Start Schists. It appears not unlikely that the Armorican line represents a revival on an older trend-line of pre-Cambrian date, extending from Britanny through the Channel tract, and including the isolated Start area.

The post-Carboniferous movements which have set up slaty cleavage in the Devonian rocks lying north of the Start area can have effected but little mineralogical change in the Start rocks; but the movements may well have given rise to more complicated mechanical structures in them, especially in the mica-schists.

The question of the origin of the quartz and quartz-albite veins in the mica-schists, and to a less extent in the Green Schists, is one of some interest. The abundance of quartz-veining in the former might well be attributed to circulating solutions during metamorphism. Quartz-veining, moreover, is not absent from the Devonian rocks, and appears to coincide in direction with the cleavage of these rocks. It is highly probable that the quartz-veining in the mica-schists, as now observed, is the resultant of circulating solutions during the folding movements which brought

[1] 'The Geology of the Lizard & Meneage' Mem. Geol. Surv. 1912, p. 215.

about metamorphism, and of solutions acting during the post-Carboniferous activity, the evidence of which is their presence in the adjacent Devonian rocks.

Quartz-albite- and albite-veins are not infrequently met with in the mica-schists, and Ussher showed that they are also present in the Devonian rocks. These can be recognized at points north of the boundary-line (for example, at Clannacombe, and at other places as far as 2½ miles north of the metamorphic boundary).

The origin of these quartz-albite-veins is not free from obscurity:

(i) They may be considered as having their source in the epidote-albite-schists of the Start group, in which circulating solutions have dissolved albite formed from plagioclase during metamorphism, and with quartz impregnating the adjacent mica-schists as well as in the second period of movement penetrating the Devonian rocks on the north. They are much more abundant in the mica-schists than in the Green Schists, where they are rare, and the more perfect schistosity of the mica-schist group is doubtless the reason for this.

(ii) They may be considered as having their source in the post-Carboniferous intrusion of Dartmoor, and its apophyses. Although the Dartmoor granite shows little sign of alkaline affinities, it is nevertheless undoubted that the final products of granitic magma are not infrequently sodic in character. Albite-pegmatites, and albitites are known as dyke-rocks in association with normal granites.[1] In Britain the albite-pegmatites of Leinster associated with Caledonian crust-movements are examples.

The most important evidence, however, that contradicts this latter view is the absence of quartz-albite-veins in the granite of Dartmoor, or in the Devonian sediments—other than those lying immediately north of the Start boundary. The rocks of North Devon have not yet been found to contain quartz-albite-veins,[2] although quartz-veining is not infrequent, nor do such appear to be present in the sediments bounding the Dartmoor granite on the south.

We are led to the conclusion that the albite has its source in the Green Schists, circulating solutions leading to a permeation of the surrounding sediments.

The analyses of the two petrographic types of Green Schist occurring in the Start area show that these rocks are indistinguishable from normal basalts: the resemblance is complete. These types were selected from rocks free from muscovite or abundant quartz.

There can be little doubt that the true Green Schists are of igneous origin. Whether they are to be grouped as tuffs, lavas, or intrusive sills is a question of importance. Ussher saw fit to

[1] Such as those in association with the adamellites of South Australia; see Trans. Roy. Soc. S. Austr. 1919 & 1920.

[2] Dr. J. W. Evans *in litt.*

regard them as an altered series of basic igneous rocks allied to the diabases in composition, and possibly consisting in part of altered tuffs. It is in every way probable that the true Green Schists represent contemporaneous lava-flows, possibly associated with sills of dolerite. Sediments are not scarce among them, but the great thickness of bands of uniform composition, consisting solely of material of igneous origin, their persistence along the strike, and the undoubted tufaceous character of beds associated with them are all in favour of this conclusion. The epidotic knots—consisting of epidote, chlorite, calcite, and albite—which are found at various points throughout the group are most satisfactorily interpreted as metamorphosed amygdales.

The rocks that have been grouped as composite rocks have the undoubted character of basic ashes or tuffs. Abundant quartz and white mica show their relationship to the mica-schists, while they are linked to the true Green Schists in the abundance of chlorite, albite, and epidote. They show a variability of composition highly characteristic of rocks of this class, for they pass out into types practically free from igneous material, assuming the character of the normal mica-schists. These relations can be studied, both in the field and within the limits of a microscope-slide.

These rocks are found in all parts of the Start area, both at the base and at the top of the thick bands of Green Schists, and also intercalated within them.

The metamorphic features of the Start Schists are among the most characteristic of those of low grades of dynamic metamorphism, and the resultant rocks find a place in the 'epi-zone' of U. Grubenmann's classification. The mica- and quartz-mica-schists correspond in all essentials to the group of rocks classified by Grubenmann in his 'upper zone' as sericite-albite-gneisses. In particular, we may note the general absence of biotite in these rocks, and the accompaniment of sericite by weakly coloured chlorite and less abundant albite, the latter normally in intimate association with quartz.

An unusual type is the porphyroblastic albite-mica-schist from Bolt Head, in which the porphyroblasts of albite are clouded with carbonaceous inclusions often zonally arranged. There is clear evidence that these porphyroblasts have developed *in situ*, including swarms of carbonaceous particles during growth.

The higher grade of metamorphism represented by the presence of biotite, metamorphically developed from sericite and chlorite, as I have already noted, is never reached.[1]

Among the true Green Schists two distinct types have been recognized, the one characterized by chlorite, and the other by hornblende.

Chlorite-epidote-albite-schists are the most characteristic low-grade dynamically-metamorphosed equivalents of basic igneous

[1] Exception can here be made for the beginning of biotite formation seen only in a few slides of mica-schists. This incipient development is found in the immediate vicinity of grains of iron-ore.

rocks. The conversion of pyroxene to chlorite, and of calcic plagioclase to epidote, zoisite, and albite, is the normal result of these conditions. Among these rocks there is seldom reason to believe that chlorite is secondarily developed from hornblende.

The development of chlorite at the expense of pyroxene may have been early initiated, as a weathering reaction in the original lavas and tuffs before their metamorphism. In none of these rocks can any evidence of original (but now relict) minerals be observed, nor are there preserved original igneous textures. In the complete recrystallization, following the chemical changes, original minerals and textures have been completely obliterated. A pseudoporphyritic texture is not infrequently observed; but there is every reason to believe that this is a porphyroblastic texture developed during metamorphism. The best examples of this are the porphyroblastic albites in the green schists already described. Original ilmenite or titanomagnetite in the igneous rocks gives rise to titanite in the metamorphosed types. The production of chlorite from pyroxene, particularly augite, has set free abundant lime, which has appeared both as epidote and calcite where carbon dioxide was present. Calcite is a common constituent of these schists. In metamorphism under directed pressure, it has often crystallized in narrow streams among the remaining minerals. Its subsequent removal by weathering gives (as already noticed) a pitted and cavernous appearance to some of the rocks, besides accentuating their schistosity.

Only the larger features have been preserved, such as the nodular masses of epidote, chlorite, calcite, and albite, which are here interpreted as metamorphosed amygdales.

In the next stage of metamorphism, hornblende largely takes the place of chlorite. Already in the chlorite-epidote-albite-schists, hornblende begins to appear as fine acicular needles associated with chlorite or developed poikiloblastically within albite. With increasing metamorphism, hornblende increases in amount, and the individual crystals themselves become larger: ultimately they may appear as porphyroblasts. Rocks of this type are distributed throughout the area where the Green Schists are exposed, and it is impossible to present a map showing zonal distribution of either type.

The development of hornblende, of an aluminous type (as shown by the analysis), is the result doubtless of a chemical interaction between chlorite and calcite, or between chlorite and epidote. In both these reactions it is clear that additional silica is required, and is provided by quartz. Small amounts of quartz can usually be detected interspersed among the albite-grains of the Green Schists.

Not infrequently have I observed that the development of abundant amphibole is accompanied by a noticeable increase in the lime content of the plagioclase, oligoclase, or oligoclase-albite, appearing with or without albite. This is in accord with the higher grade of metamorphism, and the increasing stability of the more basic felspar as metamorphism progresses.

In the third type of rock, the rocks of composite origin, the minerals developed include those characteristic of the Green Schists, and the essential minerals of the mica-schists. The lowest grade of metamorphism is represented by the quartz-muscovite-chlorite-albite types. The succeeding stage is the development of red garnet which (as previously noted) may reach 1/16 inch in diameter, forming idioblasts in a muscovite-chlorite ground-mass. This garnet is an almandine containing 5·5 per cent. of manganous oxide, corresponding to a spessartine content of 12·8 per cent.

There is no indication that biotite has ever been a constituent of these rocks, nor that chlorite has been secondarily derived from it. Almandine is the common garnet of metamorphosed argillaceous sediments, and as such appears in rocks showing progressive metamorphism after biotite has developed. This is abundantly clear from the work of Mr. G. Barrow in the South-Eastern Highlands of Scotland,[1] and receives confirmation from the zones of metamorphism in the Trondhjem district of Southern Norway.[2]

The presence of a notable content of manganese in the metamorphosed sediment appears, however, to lead to an earlier development of garnet, with the result that the order of development of these two minerals is reversed. This receives support from other regions, for example in the spessartine-bearing phyllites of the Ardennes (as described by Renard), and still more recently in the Stavanger district of Southern Norway. In this area Prof. V. M. Goldschmidt has shown that progressive metamorphism in the Cambro-Silurian sediments has led to the development of zones characterized in ascending sequence by chlorite, garnet, and biotite. Analysis of the garnets of these rocks shows that they contain notable amounts of the spessartine molecule.

The highest stage of metamorphism in the composite rocks is that of the garnet-bearing types. The source of the manganous oxide of these garnets is doubtless the sedimentary material, and not the part contributed by the igneous rocks. The garnet owes its development to chlorite combined with manganiferous material in the sediment. This is the more probable when it is considered that garnet never appears in the true Green Schists rich in chlorite, but devoid of sedimentary detrital material.

Hornblende is a rare constituent of this type of rock, and when it does appear, is associated with chlorite usually free from muscovite. Its rarity here, when compared with its almost universal presence in the true Green Schists, is noteworthy. It is highly probable that in rocks of this composition, hornblende appears characteristically in a higher grade of metamorphism, and later than in the associated Green Schists.

Among the minerals of igneous rocks, hornblende and muscovite appear to be mutually exclusive, and, while we are unable to apply completely the same restriction in metamorphosed rocks, there are

[1] Proc. Geol. Assoc. vol. xxiii (1912) pp. 274–79.

[2] V. M. Goldschmidt, Vidensk. Selsk. Skrifter, No. 10 (1915) pp. 36–37.

indications that common hornblende and muscovite are infrequent associations in rocks of metamorphic origin. Among those rocks in which hornblende and white mica are known as characteristic associates, the amphibole is in many cases a glaucophane, or the white mica has been proved to be the sodic paragonite.[1]

With increasing metamorphism in the composite rocks of the Start area, garnet appears after chlorite, and takes the place of the hornblende in the true Green Schists.

The mineralogical constitution of the three groups of rocks in equivalent grades of metamorphism [may be compared in the following synopsis :—

<table>
<tr><th>Mica-Schists.</th><th>Green Schists.</th><th>Schists of composite origin.</th></tr>
<tr><td rowspan="2">Quartz.
Muscovite.
Chlorite.
[Albite.]</td><td>Chlorite.
Epidote.
Albite.
{ Hornblende.
Titanite. }</td><td>Chlorite.
Muscovite.
Albite.
Quartz.
{ Epidote.
Titanite. }</td></tr>
<tr><td>Hornblende.
Epidote.
Albite.
{ Chlorite.
Titanite. }</td><td>Garnet.</td></tr>
</table>

In the succeeding stages which are not represented in the Start Group, biotite would presumably appear in the mica-schists and composite rocks, and hornblende as a characteristic constituent of the latter class would appear still later. Evidence for this is supplied in the metamorphosed green beds of the Highlands, and in the metamorphosed sediments of the Stavanger district of Norway.

VIII. Comparison with other Green Schist Areas.

The classical work of K. A. Lossen[2] on the metamorphosed diabases of the Eastern Harz, and of G. H. Williams[3] on the greenstone schists of the Lake Superior region, has led the way to

[1] See especially U. Grubenmann, 'Ueber einige Schweizerische Glaukophan-Gesteine' Festschrift H. Rosenbusch, 1906, p. 11; *id.* 'Die Kristallinen Schiefer' 1910, p. 201; T. J. Woyno, Neues Jahrb. Beilage-Band xxxiii (1911) pp. 180 *et seqq.*; and E. Greenly, 'The Geology of Anglesey' Mem. Geol. Surv. vol. i (1919) p. 117.

[2] 'Erläuterungen zur Geologischen Specialkarte von Preussen & den Thüringischen Staaten' 1882 83 (Pansfelde & Wippra sheets); and *id.* Jahrb. K. Preuss. Geol. Landesanst. 1883.

[3] Bull. U.S. Geol. Surv. No. 62, 1890.

a clearer understanding of the chemical and structural changes attending the dynamic metamorphism of basic igneous rocks. Since that time the investigations of Swiss petrologists have shown that Green Schists are widely developed in the Alpine mountain-zones, and have clearly indicated their derivation from lavas, intrusive sills, and associated tuff-beds. In all these cases it is obvious that the typical epidote-albite-chlorite-schists (prasinites) are the most characteristic low-grade dynamically metamorphosed equivalents of basic igneous rocks. In comparing the Green Schists of the Start area with like rocks of other areas, it will suffice, however, to refer to rocks developed first in the British area, and to a single area from Southern Norway involved in the Caledonian fold-movements.

(i) The Lizard Area.

The only area of rocks in the South of England which can bear comparison with the Start district is that of the Lizard. Among the pre-serpentine rocks of this area are developed mica-schists with intercalated tuff-beds, sills, and possibly lava-flows, and the great group of hornblende-schists which enclose the serpentine on the north and south.

The mica-schists of the Old Lizard Head Series bear comparison with the Start mica-schists, while the hornblende-schists considered by Dr. J. S. Flett as originally lavas and sills are chemically identical with the Green Schists.

The rocks of the Lizard are, however, in a higher state of metamorphism. The intrusion of the Man-of-War gneisses, and still later the serpentine, has led to the development of contact-minerals in both types of rocks, wherefore mineralogically they differ notably from the Start Group, in which the minerals developed are those characteristic of the upper metamorphic zone of crystalline schists.

Apart from this divergence in the metamorphic history of the Start and Lizard areas, the sequence of beds and similarity in origin of the rocks of both areas render it not improbable that the two groups of rocks may be of the same age.

(ii) The 'Green Beds' of the Scottish Highlands.

Mineralogically, the Start Green Schists and their accompanying schists of composite origin bear a close comparison with the 'green beds' of the Highlands. The officers of the Geological Survey have seen fit to regard these rocks as being of sedimentary origin, and produced directly from the erosion of the more basic portions of an igneous complex.[1]

Some of these rocks are microscopically indistinguishable from the schists of composite origin in the Start Group. The mineralogical associations of rocks of this type should allow of their use as

[1] See especially Mem. Geol. Surv. Scot. (Sheet 37) 1905, p. 18.

indicator-beds in areas of progressive metamorphism, and the range of metamorphism expressed in the 'green beds' of Scotland provides a clearer view of the grade of alteration impressed upon the Start Group. This range of metamorphism is very clearly indicated in the exposures of the 'green beds' in Central Perthshire, as at Aberfeldy and north-east of Loch Katrine. Proceeding northwards, one notes that the grade of metamorphism is gradually increased.[1] This can be very clearly recognized from a suite of rock-sections in the collection at the Sedgwick Museum, Cambridge. The order of increasing metamorphism is supplied in the following rocks:—

11935	Chlorite-albite-schist [muscovite, epidote].	North-west of Bienacreag, Loch Lubnaig.
11898	Chlorite-biotite-albite-schist [muscovite, epidote].	East of the head of Loch Lubnaig.
11934	Biotite-albite-schist [epidote].	Eastern end of Loch Katrine.
6908	Garnet-biotite-albite-schist [chlorite].	West of Loch-na-Craige, Aberfeldy.
11936	Garnet-biotite-hornblende-schist.	South-east of Aberfeldy.

This series illustrates very clearly two important points when we are considering the analogous rocks of the Start area. First, we may note that the appearance of hornblende is delayed, as in the Start Schists. It is highly probable that in the use of hornblende as a zonal mineral, the presence or absence of sericite in the original sediment or rock must be considered.

The second point illustrated is the order of appearance of garnet. In these rocks it has followed biotite, thus conforming to the normal order. In the metamorphism of basic igneous rocks practically free from potash, the order of development would appear to be chlorite—hornblende—garnet, this garnet being an isomorphous mixture of grossular, pyrope, and almandine; but, where a notable content of potash has been present (as in tufaceous types), the order is

$$\text{chlorite} \left\langle \begin{array}{c} \text{biotite—garnet} \\ \text{(Al.)} \\ \text{garnet—biotite} \\ \text{(Sp.)} \end{array} \right\rangle \text{hornblende,}$$

according as the garnet is predominantly an almandine, or contains notable quantities of the spessartine molecule.

(iii) The 'Mona Complex' of Anglesey.

Among the pre-Cambrian rocks of Anglesey, which Dr. Greenly has styled the Mona Complex,[2] there are petrological types which have analogues in the Start area. The Gwna green schists (*op. cit.* p. 67) bear a close comparison with the composite rocks of the Start area. The intimate mixtures of chlorite and white

[1] Mem. Geol. Surv. Scotl. (Sheet 55) 1905, pp. 13, 110.
[2] 'The Geology of Anglesey' Mem. Geol. Surv. vol. i (1919).

mica and the presence of albite among the quartz-grains are characteristic features of both groups of rocks. The Anglesey rocks have been regarded as sediments containing an admixture of volcanic dust. In a less degree the green mica-schists of the New Harbour Group present comparable features; but a higher grade of metamorphism is indicated by the abundant green biotite.

The true Green Schists of the Start area and the basic schists of the Gwna Group (*op. cit.* p. 77) are obviously rocks of similar origin, and both types (the chlorite-epidote and the hornblende-epidote-albite-schists) are represented. The analyses of these basic Gwna Schists agree very closely with those of the Start area.

It is, however, in the abundance of quartz- and quartz-albite-veins in the green mica-schists, the Gwna green schists, and the mica-schists of the Penmynydd zone of metamorphism, that the closest relation with similar veins in the Start Group is found, and their ascription to segregation processes during metamorphism is in accord with the evidence obtained from the Start area.

(iv) The Green Schists of Western Norway.

The investigations of Norwegian geologists (notably Hans Reusch, C. F. Kolderup, and V. M. Goldschmidt) have shown that a great group of Green Schists forms a zone in Western Norway, extending from the vicinity of Stavenes (61° 30′ lat. N.) southwards to the Stavanger region (59°), in which area their development has been investigated by Goldschmidt. These rocks, with underlying phyllites and mica-schists, are of Ordovician and Silurian age, and have participated in the Caledonian movement. The Green Schists are for the greater part hornblendic types, and are entirely comparable with the hornblende-epidote-albite-schists of the Start area.[1] They include effusive and tufaceous types, and sill-intrusions in the lower phyllites. In the latter the existence of definite zones of metamorphism has been established, and, as bearing on the Start Schists, it may be noted that the normal order of (1) biotite, (2) garnet, is reversed. Analyses of these garnets very clearly show that they are not the normal almandine, but one rich in spessartine. Furthermore, in the impurer types of sediments the appearance of hornblende is again delayed. Goldschmidt notes that hornblende develops in the zone of biotite-garnet-schists, but only in the vicinity of intrusives. This sequence of events is clearly in conformity with that revealed in the composite rocks of the Start area.

[1] [Since writing the above, I have had an opportunity of studying these rocks in the field, under the guidance of Prof. V. M. Goldschmidt. In positions remote from the area of maximum metamorphism, as on Bu Island (Buöen), of the Haastein Group, the Green Schists exhibit features identical with those of the Start Group, and hand-specimens of the Norwegian rocks are indistinguishable from the Start types.]

Fig. 1.—*Porphyroblastic albite-epidote-schist.*

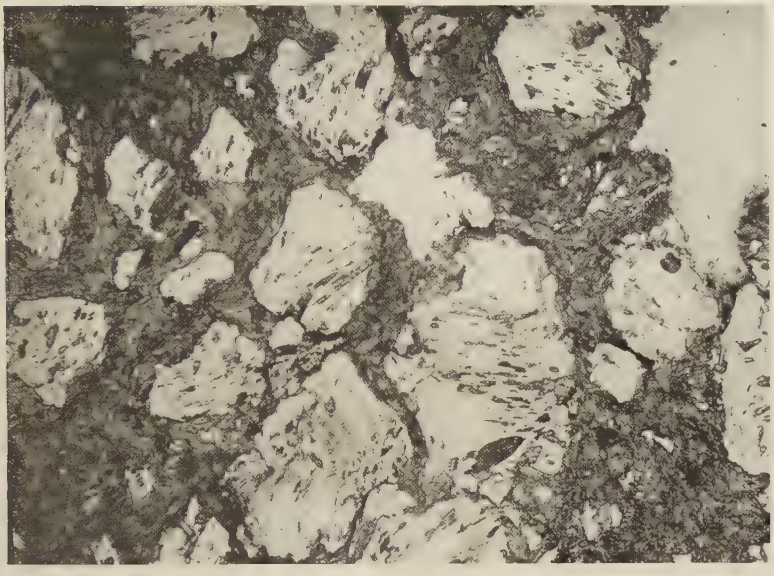
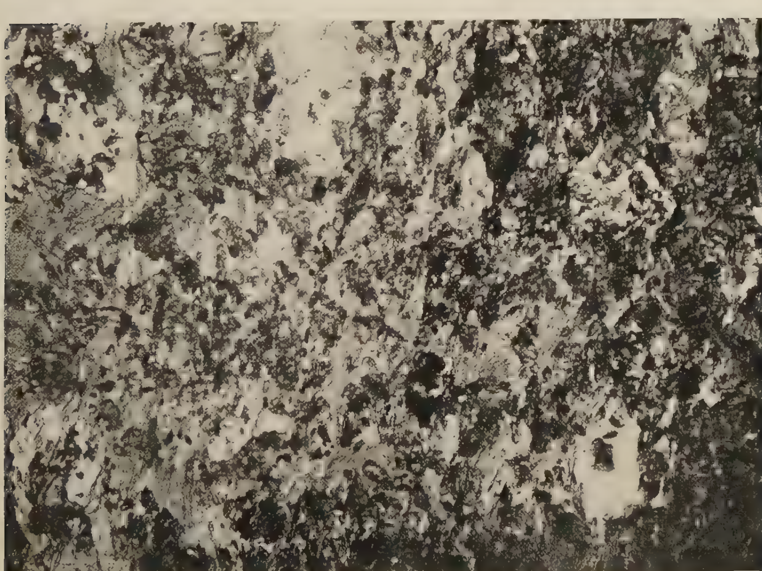


Fig. 2.—*Chlorite-epidote-schist.*



C. E. T. photomicro.

ROCKS FROM THE START AREA.

EXPLANATION OF PLATES X & XI.

Plate X.

Fig. 1. Porphyroblastic albite-epidote-schist, Leek Cove, × 32. The constituents are albite showing inclusions of epidote, chlorite, hornblende, and sphene. The abundant development of white mica associated with chlorite in parts of this rock shows that it is of tufaceous origin. (See p. 184.)

2. Chlorite-epidote-schist, Seacombe Sands, × 32. The constituents are albite, chlorite, epidote, and sphene. Associated with the chlorite are prisms of fibrous amphibole. The analysis of this rock is tabulated on p. 183.

Plate XI.

Fig. 1. Porphyroblastic hornblende-schist, Prawle Point, × 32. The constituents are hornblende in porphyroblasts, albite, epidote, sphene, and a little chlorite. The analysis of this rock is tabulated on p. 186.

2. Muscovite-chlorite-garnet-albite-schist, Langerstone Point, × 32. A schist of composite origin. The constituents are white mica, chlorite, almandine-spessartine, albite, quartz, and smaller amounts of epidote and sphene, which appear as inclusions in the garnet (see pp. 189-90).

Discussion.

Dr. J. W. Evans expressed his sense of the value of the paper. He was especially interested in the occurrence of albite in both the Green Schists and the quartz-albite-veins. He believed that this was due in both cases to the effects of pressure on the soda-lime-felspars of the local igneous rocks. He thought also that the albitization of the igneous rocks and sedimentaries, which was so marked a feature of North Cornwall, had a similar origin in the pressure-alteration of basic rocks by which the albite of the plagioclase passed into solution, and ultimately modified the composition of other rocks. He was persuaded that the magmas of the alkali- or 'Atlantic' rocks were also the result of a similar action under enormous pressure beneath the great continental shields.

Mr. H. Dewey compared the suite of rocks described by the Author with the succession of volcanic rocks in Cornwall. These Cornish rocks include spilites, albite-diabases, minverites, and frequently hornblende-picrites, which recur in the Lower Palæozoic, the Lower Devonian, the Upper Devonian, and the Lower Carboniferous Series. Their outstanding characteristic is albite-felspar, which is present in large proportions and apparently as an original constituent.

The Author had remarked upon the quartz-albite veins of the Start area. Such veins are of general occurrence in North Cornwall among the schistose Upper Devonian sediments and volcanic rocks. The district between Padstow and Trebarwith is marked by an easily recognizable series in which pillow-lavas are but little affected by shearing; but north of Trebarwith the same series

occurs in the form of schists, the pillow-lavas having been converted into actinolite-chlorite-epidote-albite-schists of a general green colour. These very frequently contain biotite, and were metamorphosed by the Bodmin-Moor granite, but otherwise resemble the Green Schists of the Start area.

In several parts of Cornwall and Devon powerful overthrusts had repeated the normal succession, and these appear to have been influenced by the resistant granite-masses. The period of overthrusting is post-Carboniferous, and may be later than the intrusion of the granite. The speaker enquired whether the Author considered that the Start Schists had also been overthrust, and, if so, at what period. He also asked when the quartz-albite veins had invaded the Devonian sediments north of the Start Schists.

Dr. G. H. Plymen remarked on the close resemblance of the hornblende-epidote-albite-schists to the schists of Sark. Prof. Bonney & the Rev. E. Hill had noted the practical absence of olivine-bearing rocks in Sark, although Sark is otherwise comparable to the Lizard area, and the Author's suggested relation of the Start Schists with olivine-basalts was interesting.

The intrusion of quartz-albite veins into the Devonian rocks seemed to suggest post-Devonian metamorphism. If the Author had reason to hold this opinion, it might have important bearing on the period of metamorphism in the Channel Islands, especially as no metamorphic rocks were at present known in the basement Cambrian conglomerate of either Jersey or Alderney.

The Author thanked the Fellows for their kind reception of his paper. In reply to Mr. Dewey, he stated that he felt that the exact nature of the movement along the metamorphic boundary, whether overthrusting or normal faulting, was still an open question. The boundary evidence, so far as he was able to interpret it, did not support the view of overthrusting. The point raised by Dr. Plymen was of considerable interest.

The albite- and quartz-albite-veins in the Devonian sediments lying north of the Start Schists were, in his opinion, attributable to circulating solutions during the Armorican folding movement in which the Devonian rocks were involved, the albite being drawn from the Green Schists immediately to the south. He was of opinion that this movement, while possibly giving rise to more complicated mechanical structures in the Start Schists, effected but little mineralogical change within them.

9. *The* Petrography *of the* Cretaceous *and* Tertiary Outliers *of the* West *of* England.

By Percy George Hamnall Boswell, A.R.C.S., D.Sc., F.G.S., George Herdman Professor of Geology in the University of Liverpool. (Read June 14th, 1922.)

Contents.

I. Introduction.

The significance of the outliers of Cretaceous and later age resting on the Palæozoic strata of Devon and Cornwall has been frequently noted, especially with reference to the evidence yielded by them of the extent of the great marine transgressions. The details of their petrology, considered in relation to their present altitude and geographical location, are dealt with in this communication, and an attempt is made to throw light on the conditions of their deposition and the source of their constituents. Lying as they do, around and among some of the most important igneous masses in the country, they may be expected to afford evidence regarding the stability of detrital minerals and of the source of constituents in sediments of the same age, but of wider geographical distribution. A comparison of the petrography of these outliers with that of the Greensand, Eocene, and Pliocene strata farther east has therefore been instituted.

These outliers in the West Country may be grouped thus :—

Cretaceous (Upper Greensand).
Great Haldon Hills (Devon).
Little Haldon Hills (Devon).

Eocene (? Bagshot).
(?) Marazion, near Penzance (Cornwall).
Buckland Brewer, near Bideford (Devon).
Great Haldon Hills.
Little Haldon Hills.

Oligocene (Aquitanian).[1]

Petrockstow, near Torrington (Devon).
Bovey Tracey and Newton Abbot (Devon).

Pliocene.[2]

St. Erth and Lelant (Cornwall).
Crouza Down, near St. Keverne (Cornwall).
St. Agnes (Cornwall),

together with certain deposits of doubtful age (see p. 223).

The respective heights of the upper and lower surfaces of the deposits above Ordnance-datum are as follows:—

	Upper Surface.	Lower Surface.[3]
Cretaceous.	*Feet.*	*Feet.*
Great Haldon	800 on N. to 600 on S.	750 on N. to 550 on S.
Little Haldon	600 on N. to 700 on S.	550 on N. to 600 on S.
Eocene.		
Marazion	20 to 30	? 0
Buckland Brewer .	approx. 260	200 [3]
Great Haldon	reaches 830	800 to 600 [3]
Little Haldon	reaches 810	600 to 700 [3]
Oligocene.		
Petrockstow	300	? less than 200
Bovey	never above 500	? 100 or more below Ordnance-datum
Pliocene.		
St. Erth	? 110	? 90
Lelant	180	180
Crouza Down	365	
St. Agnes.	350 to 420	? 340 to 410

II. Evidence of the Age of the Deposits.

Good general descriptions of the various deposits have been given by various authors (mentioned below), and, so far as field-evidence is concerned, little can usefully be added to their accounts.

The age of the Cretaceous deposits was determined as Upper Greensand from their fauna, the zones recognized being those of *Schlœnbachia rostrata* and *Pecten asper*.[4] The presence of weathered and stained flints and of derived Chalk fossils (including *Marsupites*) in the beds of gravel capping the Haldon Hills, of carious and weathered flints in the gravels near Buckland Brewer,

[1] I have followed Clement Reid, in the Geological Survey Memoir (1913), in grouping the Aquitanian with the Oligocene. It is now generally referred to the Miocene age.

[2] These deposits have been dealt with recently by Mr. H. B. Milner. Notes on them are here inserted for completeness and for comparison.

[3] Owing to a certain amount of sagging on the slopes of the hills, the difference between the levels of the upper and those of the lower surfaces is often far greater than the actual thickness of the deposits.

[4] 'The Cretaceous Rocks of Britain: vol. i' Mem. Geol. Surv. 1900, p. 218; 'The Geology of the Country around Newton Abbot (Sheet 339)' Mem. Geol. Surv. 1913, p. 93 (hereafter referred to as the 'Newton Abbot Memoir').

and their abundance in a rolled condition in the gravel at Marazion, definitely indicated the post-Cretaceous age of each of these deposits. In their general character, the gravels differ much from the Pliocene strata of Cornwall and the Oligocene of Devon, but they bear certain resemblances to some of the Eocene gravels of the South-East of England. Their probable age was, therefore, considered by Clement Reid to be Eocene.[1]

The plant-remains found in the lignites interbedded with the clays of the Bovey basin have established the age of the deposits as Oligocene (Aquitanian).[2] They had been considered, however, to be Middle Eocene, like the Bournemouth leaf-beds, by J. Starkie Gardner, and were formerly referred to the Miocene when the Aquitanian stage formed part of that formation in the classification of Continental authors.

The lignitic clays and sands filling the Petrockstow basin are similar in many respects to the Bovey deposits,[3] and are, therefore, tentatively considered to be of the same age.

Of the Pliocene deposits, those of St. Erth carry a fauna which is considered by the majority of workers to date them as Pliocene, the exact horizon being a matter of opinion.[4] The remanié blocks of red sandstone around Lelant are similar in general characters to the red sands at St. Erth. The sediments lying on the '400-foot platform' of Cornwall at Crouza Down and St. Agnes have been referred to the Pliocene age, on account of their position and general resemblance to some of the strata at St. Erth. The arguments for the Pliocene or pre-Pliocene age of the 400-foot platform are too well-known to need recapitulation here.[5]

All the samples examined were collected by me personally. They were chosen, so far as might be, from every deposit exposed, and selected to be as representative as possible, in regard both to vertical succession and to lateral distribution. In order to save space, the individual occurrences of minerals in each sample have not been enumerated, but a summary table of occurrences for each formation is given on p. 226.

III. Petrography.

(1) The Cretaceous Deposits.

Earlier workers saw more complete sections of the Cretaceous rocks than those visible on my various visits since 1912. The lowermost beds recorded by H. J. Lowe, A. J. Jukes-Browne, and Clement Reid have been obscured, and have therefore not

[1] Newton Abbot Memoir, p. 102. [2] *Ibid.* p. 106.

[3] W. E. A. Ussher, Q. J. G. S. vol. xxxiv (1878) p. 457; Trans. Devon. Assoc. vol. xi (1879) p. 442.

[4] P. F. Kendall & R. G. Bell, Q. J. G. S. vol. xlii (1886) p. 201; A. Bell, Trans. Roy. Geol. Soc. Cornwall, vol. xii (1898) p. 133; R. B. Newton, Journ. Conch. vol. xv (1915) p. 56; and C. Reid, 'Pliocene Deposits of Britain' Mem. Geol. Surv. 1890.

[5] H. Dewey, Q. J. G. S. vol. lxxii (1916–17) p. 63.

been examined petrologically. The most complete section, which is perhaps typical, despite the fact that the beds are rather variable, is that exposed in the Goyle, south-west of Woodlands and north of the Racecourse, on the Great Haldon Hills.[1]

On the Little Haldon Hills the best section at present visible is that in Smallacombe Goyle on the eastern flank. The base of the deposit is not reached, but a greater thickness of beds is seen than on the Great Haldon. The section recorded by Mr. H. J. Lowe in 1899 is reproduced briefly below; but, at the present time, only the upper portion of Bed 5 and the succeeding beds are visible:—

	Thickness in feet.
1. Surface-soil and flint-gravel	7 to 9
2. Sharp coarse yellow sand, containing large irregular masses of chert	30
3. Brownish sand without chert	15
4. Rather coarse brownish greensand, with large grains of glauconite, including some lenticular seams of white sand.	7
5. Denser and greener sand with lumps of cherty stone, current-bedded and showing some layers of darker green, owing to the preponderance of glauconite-grains; passing down into glauconite-sand containing flattish lumps of glauconite-sandstone	40

Certain of the sandy beds, notably those containing glauconite, are moderately graded, but the majority of the deposits show little evidence of sorting.

Mechanical analyses of numerous samples were made, using single-vessel elutriators (a separate vessel for each grade). Some typical results, chosen to show the variation in composition, are represented graphically in fig. 1 (p. 209).

The minerals recognized in the Cretaceous deposits are enumerated in the table on p. 226.

The residue of density greater than 2·8 is abundant in all samples, and is either black and lustrous as a result of the great quantity of schorl present, or deep green from the abundance of glauconite.

In the following notes, the mineral order adopted is approximately that of relative abundance.

T o u r m a l i n e (s c h o r l) usually constitutes the bulk of the residue. The grains are of all sizes up to 0·3 mm. in diameter, but are generally many times larger than the other heavy detrital minerals. The mineral occurs in irregular fragments, stumpy prisms, networks of needles, or spherically radiating fibres. It displays a wonderful range of colour, among the varieties seen being grey, yellow, brown, pink, blue, green, and purple. Most of the grains show the strong absorption characteristic of tourmaline. A few approximately basal flakes occur, and among these nearly triangular, zoned crystals have been noted.

In many samples, m u s c o v i t e is, after tourmaline, the most abundant heavy mineral; in others glauconite. The muscovite is

[1] Newton Abbot Memoir, p. 94.

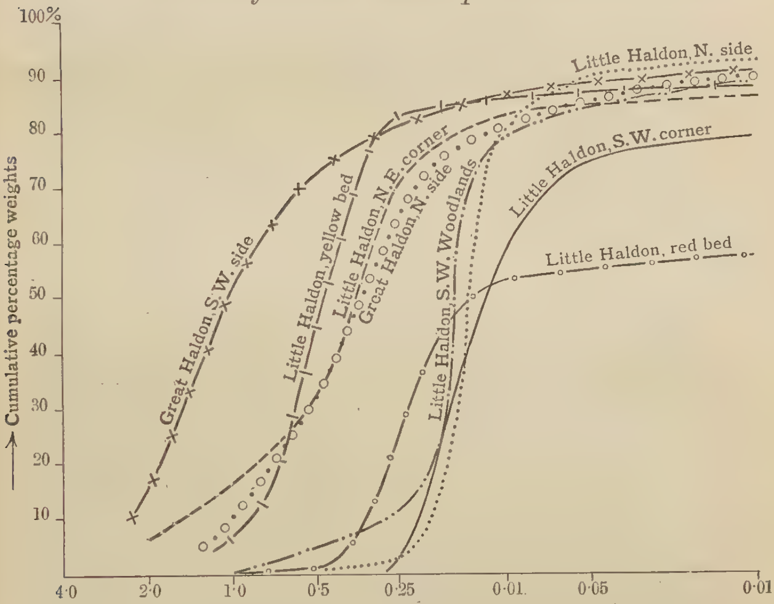
always biaxial, and is sometimes full of inclusions. Hexagonal flakes occasionally occur.

Glauconite occurs as deep-green irregular or mammillated grains, or as casts of foraminifera. Very fine examples, 0·5 to 0·6 mm. in diameter, are seen in samples of sand from the northern end of the Great Haldon Hills.

Zircon is present in all samples, and occurs both in rounded grains, and as crystals with well-developed faces. Brownish grains resembling zircon in form may be xenotime.

Rutile is not so abundant, but the foxy-red variety is often present. The yellow variety is less plentiful.

Fig. 1.—*Graphical representation of typical mechanical analyses of the Greensand deposits.*



Yellow tabular anatase is occasionally seen, and the indigo-blue variety of the mineral occurs as flat tablets on the basal plane, which is bevelled and truncated by the first- and second- order pyramids. Pyramidal grains also occur.

Andalusite, in clear glassy grains, sometimes prismatic and showing blood-red or pink pleochroism, is frequently present. Grains dusky with inclusions have been noted only occasionally.

Kyanite, which occurs in the well-known tabular grains with cross-cleavage, is on the whole rather uncommon, but is abundant at certain horizons. It is never so plentiful as in the Pliocene deposits of St. Erth.

Staurolite is frequently met with, and in some samples is extremely abundant. The grains are often large (0·2 mm. to 0·3 mm. in diameter) and irregular in shape, but never ragged like many of those described from the neighbouring Trias.[1] They are delicately pleochroic in golden yellows, and usually show the emergence of a single optic axis.

When topaz occurs (as in certain samples from Smallacombe Goyle), it is often plentiful, and the grains are of large size, irregular form, clear and glassy. When the shape of the grains is determined by the basal cleavage on which the grains lie, they yield a biaxial directions-image, the emergences of the optic axes being usually on the edges of the field, owing to the wide optic axial angle. Frequently, however, the grains do not lie on the basal plane, but are chips or wedge-shaped fragments approximating to that form (see fig. 3, p. 214). Then they yield a partial figure, but not the emergence of a single optic axis. The high refractive index, low birefringence, and positive sign serve to confirm the identification. In certain cases the grains are full of dusky inclusions.

The clear and non-pleochroic andalusite bears some resemblance at first sight to topaz, but it may be distinguished by the negative sign, the greater fraying of its edges, the inclusions, etc. Although its average refractive index is higher than that of topaz, more light rays are reflected from the edges of the topaz-grains, because these edges are almost perpendicular to the glass slip. The fainter borders of the andalusite can be shown by focussing to be due to the wedge-shaped edge of the grains.

Of the iron-ores, magnetite is absent, and ilmenite is, on the whole, rare. The latter mineral is either black and lustrous, or altered to limonite and leucoxene.

Brookite occurs in several samples. The grains are small and flat, and not bounded by crystal-faces. The colour is from brownish to that of straw, but the characteristic basal striation is frequently absent. The grains display excellently the typical dispersion; they do not extinguish completely, and are uniaxial for green light.

Corundum is a rare constituent. When present it is recognized by its relatively high refractive index, its form (usually flat and hexagonal in grains resting on the basal pinacoid), and its patchy 'royal-blue' colour. In prismatic grains it is pleochroic.

Particoloured red and yellow cassiterite has also been observed.

Garnet has been noted, but very seldom, and then as solitary grains, which are generally colourless or faintly pink. They are either isotropic, or, rarely, are anomalously birefringent.

Chert in grains showing aggregate polarization of chalcedonic type is not uncommon.

Among those minerals that are abundant in the rocks of Devon

[1] H. H. Thomas, Q. J. G. S. vol. lxv (1909) p. 234.

and Cornwall, but absent (so far as my observation goes)[1] in the Greensand of the Haldons, are amphiboles (hornblende, actinolite), pyroxenes, biotite, chlorite, and epidote.

In summarizing the petrological characters of the Greensand of the district, it may be said that—

(1) The heavy detrital minerals are coarse in grain and abundant in quantity.
(2) No important and systematic variation in quantity or character of the residue is noted, either laterally over the small area covered, or vertically through the very different lithological divisions.
(3) Tourmaline of all tints, shapes, and sizes is by far the commonest constituent.
(4) Muscovite, and occasionally glauconite, is very abundant, occurring in large grains.
(5) Andalusite (mainly pleochroic) and staurolite are exceedingly plentiful. Topaz is rather less abundant.
(6) Kyanite occurs, but is rather irregular in its distribution. It is in some cases very abundant; in others it is rare.
(7) Garnet is extremely rare or absent.
(8) Magnetite is absent, and ilmenite often rare.
(9) Amphiboles, pyroxenes, biotite, and chlorite appear to be absent.

Of the minerals enumerated above, the subordinate importance of magnetite is general in sediments, and possibly also in many igneous rocks.[2] The rarity of ilmenite is noticed again on p. 223. The rarity of garnets, a feature which the Cretaceous System of the West Country shares with the Eocene, Oligocene, and Pliocene (see later, p. 221), is noteworthy and very difficult to explain in view of the abundance of garnet in the rocks of Devon and Cornwall (for instance, in the Lizard schists), in metamorphic aureoles round the granites, and in contact-rocks near dykes and other intrusions, etc. The difficulties are not decreased when it is remembered that the mineral is abundant in Britanny, where it is associated with staurolite, tourmaline, and other stress-minerals.

Zircon and rutile are widespread in sediments, and are of little determinative value as regards source of constituents. The origin of the large quantities of rutile in sedimentary rocks is at present unexplained.

Anatase and brookite are interesting mineralogical curiosities, but their wayward incoming and disappearance also supports the view that they have little or no determinative value.

Tourmaline, muscovite, andalusite, and topaz occur abundantly in the Dartmoor and Cornish granites and other aureoles. The presence of these minerals in large quantities in the sediments here described might, therefore, be expected. On general evidence, such as the presence of pseudostratification indicated by the porphyritic felspars, etc. of the uppermost layers of granite, it is

[1] Although it is always dangerous to reason from the absence of certain minerals, the arguments are frequently not vitiated if the expression 'of great rarity' be substituted for 'absence'.

[2] See, for example, R. H. Rastall & W. H. Wilcockson, Q. J. G. S. vol. lxxi (1915–17) p. 620, table.

considered that the mass of Dartmoor has suffered relatively little denudation, and that it was probably first exposed only in Tertiary times.

Corundum and staurolite have both been observed in Devon and Cornwall as produced by the alteration of argillaceous sediments by dyke-rocks[1]; but, while such occurrences would be sufficient to account for the rare presence of corundum in the Cretaceous (and also Eocene), the quantity of staurolite in the Cretaceous deposits is far too great to be explained thus. A staurolite-bearing series of metamorphic rocks such as those in Britanny could alone account for the quantity observed in the Greensands. In short, as Dr. H. H. Thomas deduced in the case of the staurolite in the New Red rocks of Devon,[2] we must turn to Britanny or a part of the old 'Armorica' now submerged beneath the waters of the English Channel for the source of this mineral. It is noteworthy that, while clear, glassy, pleochroic andalusite is very abundant, the variety dusky with inclusions which is so commonly found around Dartmoor is only met with occasionally. A Cornish origin for some, at any rate, of the clear grains is adumbrated.

Kyanite also is not indigenous to the West Country. Although the mineral is not abundant in the Upper Greensand of Haldon (being by no means so plentiful as in the Lower Greensand over its whole outcrop throughout England), its presence can be explained only on the assumption of currents from an extra-British land-area lying on the south-west.

The absence of biotite, hornblende, pyroxene, etc., may be correlated with the rarity of garnets; or, as seems more probable, may be due to the decomposition of these minerals either before or after the deposition of the Cretaceous sediments.

Despite the proximity of granite containing orthoclase and oligoclase, felspars are usually absent from the Cretaceous deposits. Only calc-alkali felspars of average refractive index μ_D 1·540, referable to oligoclase, are found, and those but rarely.

(2) The Eocene Deposits.

Marazion.—The evidence for the supposed Eocene age of the gravels, clays, and sands occurring between Marazion and Penzance (probably connected with the north-and-south through-valley) has been given in detail by Clement Reid.[3] The gravelly material occurs at about 20 to 30 feet above Ordnance-datum, and consists of brown-weathered flints, fragments of Greensand chert, local Palæozoic rocks, etc., embedded in sand or loam. Reid hazarded the opinion that the matrix (which he considered was not the

[1] H. G. Smith, Q. J. G. S. vol. lxxii (1916–17) p. 77; J. Parkinson, *ibid.* vol. lix (1903) p. 408.

[2] H. H. Thomas, *ibid.* vol. lviii (1902) p. 630.

[3] Q. J. G. S. vol. lx (1904) p. 113, and 'Land's End (Sheets 351 & 358)' Mem. Geol. Surv. 1907, p. 68.

original matrix) 'probably forms part of the raised beach which fringes Mount's Bay'.

The minerals identified are enumerated in the table on p. 226.

On the whole, this is a richer assemblage than that of either the Eocene or the Cretaceous of Devon, and would appear to be in the main locally derived. Kyanite and staurolite are less abundant than in the Pliocene and Cretaceous deposits. Garnets, both colourless and pink, are not uncommon, and, in addition to the minerals obtained from the granite areas (andalusite being very abundant) and the Armorican land-mass, we have hornblende, serpentine, and epidote. These last-mentioned minerals were probably derived from the rocks of the Lizard, or from that direction.

Examination of the recent beach-sand from Marazion shows that the mineral assemblage is less rich, and the detrital minerals rather coarser, than in the deposit above described. There are also differences in composition, but these do not appear to be essential. In short, the beach-sand might well have been derived from the Marazion gravel. The petrological evidence bearing on the possible Eocene age of the matrix of the gravel is inconclusive.

Buckland Brewer, near Bideford.—Loamy deposits and red sands containing Chalk-flints have been described from near Orleigh Court, Buckland Brewer (North Devon). The deposits lie at approximately 260 feet above Ordnance-datum, and are of no great thickness. They rest upon Devonian slates, and can now be observed only in sand-pits in the Rookery and in roadside and hedgerow sections. The flints contained in the loam and sand are weathered to a brown and carious condition. In general characters, the mixture resembles certain of the Eocene and Pliocene deposits farther east, or in places even the 'Clay-with-Flints'.

After the clay has been washed off and the material sifted, the coarse portion (greater than 1 mm. in diameter) is found to consist of fragments of grey slate (the local rock), flint-chips, jasper, and grains of transparent, white, and pink quartz, many of the last-named being rounded. The finer material is highly limonitic, and had to be cleared by boiling with dilute hydrochloric acid before separation in heavy liquids.

The minerals recognized are enumerated in the table on p. 226.

Tourmaline is by far the most abundant mineral, the grains averaging 0·2 to 0·3 mm. in diameter. Blue crystals as well as brown occur, and one grain was observed, consisting evidently of two united crystals of different orientation, such that it yielded its own interference-tints without an analyser.

Andalusite is also abundant, and occurs in clear pleochroic grains showing subconchoidal fracture and few inclusions.

Topaz in large irregular grains is not uncommon.

Staurolite and kyanite are both rare, only a single grain of the latter having been observed.

Fig. 2.—*Graphical representation of typical mechanical analyses of the Eocene deposits.*

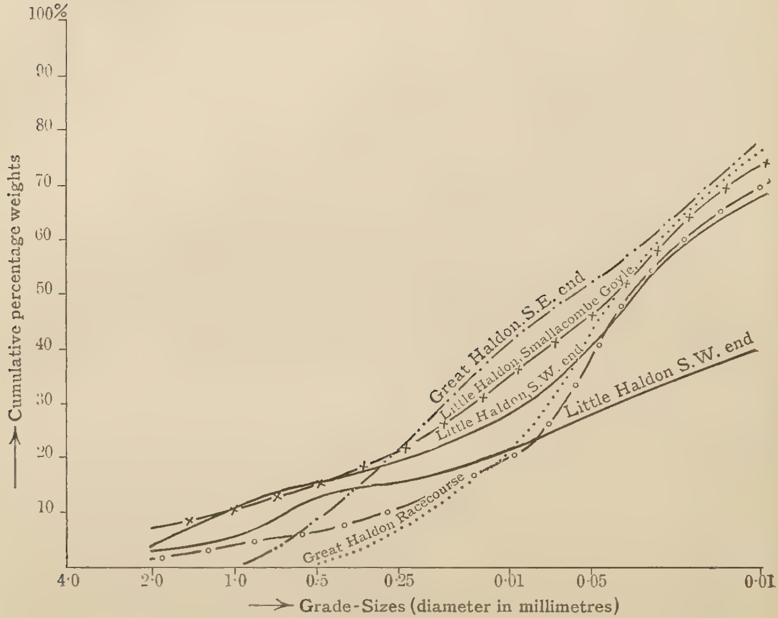
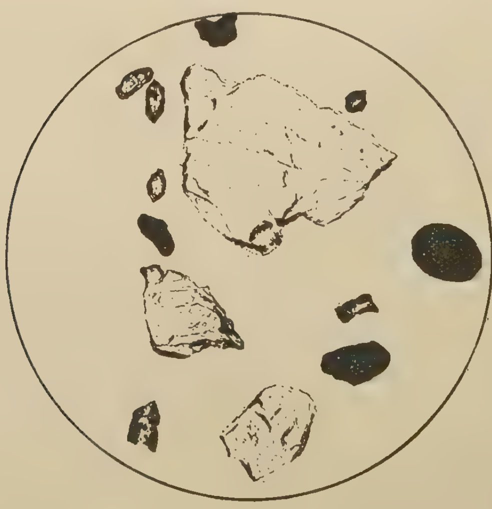


Fig. 3.—*Typical Eocene residue containing large grains of topaz : Haldon Hills.* × *80 diameters.*



Monazite occurs rarely in grains of the usual form. The identification of this mineral was confirmed spectroscopically.

Garnet is also rare, a single grain, 0·08 mm. in diameter, having alone been found.

Quartz occurs, either as large rounded grains (1 mm. or more in diameter), or in small angular chips (0·15 mm. in diameter).

All the minerals enumerated above (with the exception of the rare staurolite and kyanite, which may have been obtained from the Greensand) could have arisen from the erosion of the Dartmoor or Bodmin granite-masses.

The Haldon Hills.—Capping the flat-topped hills of Great and Little Haldon are beds of coarse gravel with a grey, yellow, or brown matrix, and occasional seams of sand and mealy clay. As Clement Reid (who described these deposits and suggested for them an Eocene age)[1] pointed out, they reach the top of the Haldons, approximately 800 feet above Ordnance-datum, but are subject to sagging round the edge. There is no evidence, however, that they descend into neighbouring valleys, and they are probably not more than 30 or 40 feet thick. The bulk of the gravel consists of large well-weathered Chalk-flints; but Greensand chert and fragments of Palæozoic rocks also occur. The wide extent of the gravels and the immense amount of flint contained in them gives some indication of the huge quantity of chalk which has disappeared.

Derived Upper Chalk fossils such as *Echinocorys* are found. The deposits are thus Tertiary in age, and, on account of their position and general similarity to certain gravels of Bagshot age, they have been referred to the Eocene.

Clay is more prevalent than sand in the matrix of the gravels, and is clearly derived from the decomposition of felspar yielded by the granite farther west. The matrix is greyish to yellow or brown when ironstained. The sands are often clayey, and are badly graded, as the accompanying graphical representation of the results of mechanical analyses indicates (fig. 2, p. 214).

The mineral assemblage is an interesting one, as indicated in the table on p. 226.

The heavy residue is usually large in quantity, and presents a lustrous black appearance due to the large proportion of schorl present. Small local differences in the relative proportions of the minerals present have been noted, but all the deposits are of the same general type. The detrital minerals are poorly graded, topaz and tourmaline being very large (see fig. 3, p. 214).

Tourmaline is exceedingly abundant, and is found in grains of all colours, shapes, and sizes. Small prismatic crystals are abundant, many being fluted.

Topaz is, on the whole, very plentiful. It occurs in large,

[1] Newton Abbot Memoir, p. 102.

colourless, glassy grains, 0·2 to 0·4 mm. in diameter: that is, considerably larger in size than the grains of most other minerals.

Staurolite is by no means plentiful. The grains are not ragged at the edges, and do not exhibit the prismatic and pinacoidal cleavage.

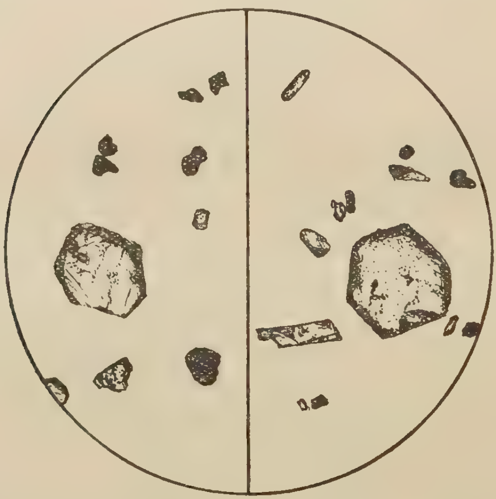
Pleochroic andalusite is rare at several localities, but on the whole is moderately abundant. Grains full of stony inclusions (? broken chiastolite) have also been found.

Kyanite is either rare or absent. The records of epidote, common hornblende, and chlorite are from single grains.

Garnet is again very rare, a solitary grain having been noted.

Anatase is not uncommon in certain localities. The variety observed was indigo-blue, and crystallized in flat tabular crystals with a small development of the pyramid faces.

Fig. 4.—*Hexagonal grains of corundum in Eocene deposits. × 60 diameters.*



a *b*

[4 *a* is from Great Haldon, western side; 4 *b* from Little Haldon, south-eastern end.]

Corundum is persistent in its occurrence as hexagonal grains, determined probably by the basal parting (see fig. 4). The 'royal-blue' colour is patchy, the refractive index high, and the grains give a negative uniaxial figure.

From the foregoing notes it is clear that there are many points of similarity between the residues of the deposits from Buckland Brewer and the Haldons, but that the Marazion residue is richer and of rather different type. We may, moreover, rule out the Marazion material, on general grounds (p. 213), as not likely to be

pure Eocene. So far as the petrology is concerned, however, the Eocene deposits of localities so far apart as Mount's Bay and the Haldon Hills might conceivably be very different.

It is satisfactory, nevertheless, to note that the petrology of the North Devon outlier resembles that of the Eocene material from the Haldon Hills. Corundum is more plentiful in the latter, and monazite in the former; but no important difference in the mineral assemblages was observed.

(3) The Oligocene (Aquitanian) Deposits.

When we turn to the two basins of lignitic clays and sands, the one near Torrington, and the other between Bovey Tracey and Newton Abbot, we observe notable differences in lithology and petrology from the deposits previously described.

Bovey Beds.—The Bovey deposits are well known, and have an extensive literature. They rest upon Devonian, Culm, and Permian rocks. In altitude they never rise to more than 500 feet above Ordnance-datum, and they have not been bottomed, although a depth of 500 feet has been proved. Clement Reid considered, too, that at least another 400 feet had been removed by denudation. The basin would thus originally have been over 1000 feet deep. The beds occupy at present a lozenge-shaped area, about 9 miles long and 4 miles broad, and they vary considerably in lithology, from fine-grained fire-clays to coarse gravels. In some of the gravelly and sandy streaks, schorl constitutes as much as 25 per cent. The results of the mechanical analyses (see fig. 5, p. 219) serve to emphasize this variation, and indicate, moreover, the incomplete character of the grading of the deposits, the bulk of which are unsorted clayey sands. Marine action or even prolonged river-action would have resulted in a certain amount of sorting, and a separation into sands and kaolin-bearing clays. The materials as they are found, however, indicate deposition of various grades, coarse and fine, resulting from the sudden arrest of streams of detritus-laden water as it entered a lake-basin practically free from currents. Only the proximity of an area of kaolinized and tourmalinized granite could have given rise to such sediments.

The heavy detrital minerals identified are enumerated on p. 226.

The quantity of heavy minerals in the different samples varies considerably, being at times far below 0·01 per cent. Where the proportion of the residue is considerable, schorl constitutes the bulk. Other minerals rarely occur in quantity. The relative proportion of the various species present does not appear to vary from Bovey to Newton Abbot.

The assemblage is actually far less rich and more restricted than the list of minerals might suggest. The only commonly-occurring minerals are the iron-ores, zircon, rutile, and tourmaline, an assemblage without definite character.

Tourmaline is exceedingly abundant. It is present in all tints, and usually in large grains (0·2 to 0·3 mm.), mostly irregular in form. One flat hexagonal blue crystal, resting on the well-developed basal plane, was observed. In certain 'pay-streaks', as noted above, the mineral forms as much as 25 per cent. of the sand or gravel. Equidimensional grains as well as needles of blue tourmaline occur frequently in these sediments, as in the Cretaceous and Eocene deposits described above.

Staurolite is, on the whole, not common, and the grains are always small. They may have been derived locally from other staurolite-bearing sediments, such as the Greensand.

Glauconite is uncommon, and is certainly detrital, its source being doubtless the marine Cretaceous deposits.

Andalusite occasionally occurs, the grains being either clear and pleochroic, or full of inclusions. In the latter case, the variety should probably be termed chiastolite. The record, however, of 'chiastolite' in the table on p. 226 refers to the discovery of several excellent crystals showing the well-known cross due to inclusions. Two of these are illustrated in figs. 6 *a* & 6 *b*, p. 220.

Topaz rarely occurs. Of tinstone several records have been made. Hornblende, epidote, and garnet are recorded from single grains.

Anatase, as might be expected, is not uncommon in these clayey beds, indigo-blue, yellow, and grey crystals having been noted. The ilmenite present is frequently altered to leucoxene.

Very large quantities of limonite occur. Most of the grains result from the decomposition of the schorl, and many are doubtless schorl-grains coated with limonite. The blue grains appear to be more easily attacked. If this is the case, it may help to explain the preponderance of brown crystals of tourmaline in sediments of various ages.

Kyanite has not been observed.

The mineral assemblage described above is thus far from rich, and could have been derived practically entirely from local deposits. The small staurolite- and glauconite-grains may have been obtained from the Cretaceous deposits of the Haldons, or from beds of the same age now removed by denudation.

Some of the andalusite and the topaz may have passed through a cycle of erosion and sedimentation, and thus have been derived from older sediments, such as the Eocene and Cretaceous; Dartmoor would supply the rest. Of the ability of these minerals to withstand such treatment, however, we have at present no proof.

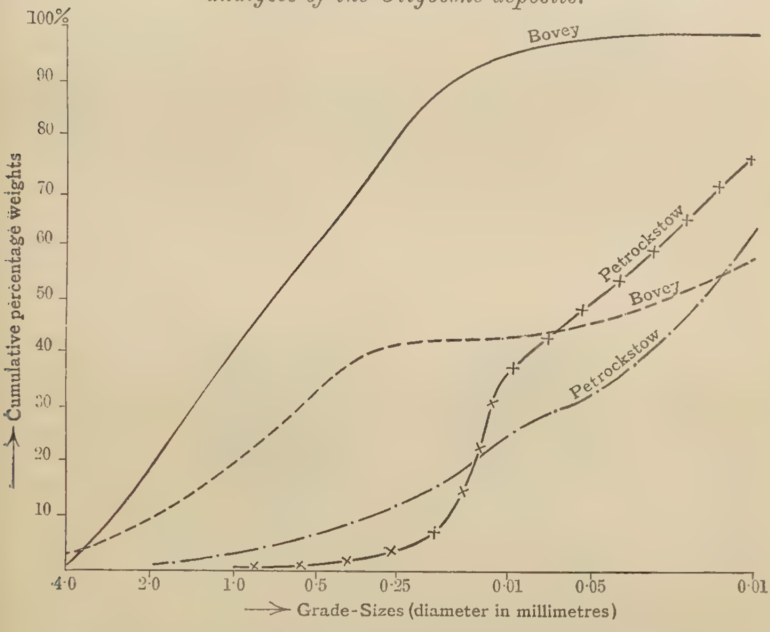
The occurrence of chiastolite showing the typical 'macle' character is unusual in British sediments, and is confined, so far as present records go, to the Bovey deposits and neighbouring gravels (Riddaford). It is noteworthy that this variety of the mineral occurs commonly in the Dartmoor aureole.[1]

[1] It occurs also, of course, in the country of the Rohans in Britanny, hence their armorial bearings.

Petrockstow Basin.—These deposits occur in a basin-like area about 300 feet above Ordnance-datum, round which the River Torridge at present follows a curious course. The basin has been proved to a depth of 100 feet, but it has not been bottomed.

The deposits are similar in general characters to those at Bovey, but clays are more prevalent.[1] Remarkable superfine sands also occur, and the lignite impregnates the clay to a greater extent than in the Bovey Basin, and is not found in such well-defined beds. The two basins were clearly filled in a similar manner

Fig. 5.—*Graphical representation of typical mechanical analyses of the Oligocene deposits.*



with detritus resulting from the rapid denudation of granite-country. Although the Petrockstow basin rests upon Devonian rocks, and is farther from Dartmoor, its materials are not essentially different from those of Bovey. They are equally poorly graded, as the graphical representation of mechanical analyses in fig. 5 indicates.

The minerals identified in the sands and clays are included in the table on p. 226.

The heavy residues are both small in amount (less than 0·01 per

[1] Chemical analyses of three of these clays are given in the 'Summary of Progress' of the Geological Survey for 1909 (1910) p. 59; see also W. A. E. Ussher, Q. J. G. S. vol. xxxiv (1878) p. 457, and Trans. Devon. Assoc. vol. xi (1879) p. 422.

cent.) and fine in grain (average diameter 0·05 mm.). Moreover, the assemblage is very restricted, and consists of stable minerals. Hornblende, epidote, and andalusite are records of single grains. Topaz is also uncommon.

Staurolite occurs in grains of diameter 0·06 mm. to 0·2 mm. One grain was notably ragged.

Glauconite occurs in grains up to 0·5 mm. in diameter, and as foraminiferal casts. It is obviously derivative from some older (probably Cretaceous) deposit.

The extremely local character of the above assemblage of minerals is again noteworthy. Glauconite and, possibly, staurolite seem to have been derived from other sediments, kyanite and garnet are absent, and pleochroic andalusite is rare. The minerals might almost have been obtained exclusively from the Dartmoor granite, and the similarity to those of the Bovey Beds needs no emphasis. Indeed, the assemblage is even poorer in species and of more restricted derivation.

Fig. 6.—*Chiastolite-grains.* × *100 diameters.*

a *b*

[6 *a* is from the Oligocene Bovey Beds, Heathfield; 6 *b* is from gravel at Riddaford, of doubtful age.]

The Cretaceous, Eocene, and Oligocene outliers thus yield evidence from their petrography of the progressive restriction of the area of rocks from which they were derived. The Cretaceous deposits are marine, often well-sorted, and contain far-travelled minerals foreign to Devon and Cornwall, as well as local varieties. The Eocene deposits are probably fluviatile, not well-graded, and possibly contain some Cornish detritus, but few 'foreign' minerals. The Oligocene deposits are lake-like in occurrence, badly graded, and of restricted and entirely local derivation.

(4) The Pliocene Deposits.

So far as our present knowledge goes, the Pliocene deposits are confined to Cornwall. Certain high-level gravels in Devon may be Pliocene, but their age has not yet been established.

The deposits occurring at St. Erth, Lelant, Crouza Down (St. Keverne), and St. Agnes are now generally accepted as of Pliocene age (see p. 207). That at Polcrebo is doubtful. Dr. H. H. Thomas has briefly recorded some of the minerals in the St. Agnes sands.[1]

The petrology of these deposits has been worked out in detail recently by Mr. H. B. Milner.[2] It is not proposed here to do more than summarize the characters that they display.

The minerals which I have identified are indicated in the table on p. 226.

The variety of minerals in the Pliocene deposits is striking, although of those recorded, garnet, phlogopite, and epidote are rare. Tourmaline and topaz are exceedingly abundant; and andalusite (while plentiful) is subordinate to kyanite at St. Erth, but is more abundant elsewhere. The distribution of kyanite varies somewhat. At St. Erth and on certain horizons at St. Agnes it is very plentiful. On other horizons at St. Agnes it is uncommon; at Crouza Down, where the minerals seem to be of more local origin, it appears to be absent.

The absence or rarity of certain locally-occurring minerals (such as pyroxenes, amphiboles, biotite, chlorite, epidote, and garnet) is noteworthy.

That the deposits are, on the whole, sorted more thoroughly than those of Oligocene and Eocene age is shown by the mechanical analyses graphically represented in fig. 7 (p. 222).

It is obvious that the progressive restriction of drainage-area and consequent impoverishment in the mineral assemblage that was characteristic of the Cretaceous, Eocene, and Oligocene deposits ceased, and indeed was actually reversed in Pliocene times. The Pliocene deposits are marine and glauconitic; they mark a widespread submergence, as demonstrated by the fauna of the blue clay at St. Erth, and they carry a rich assemblage of minerals derived in all probability from various sources. Kyanite and staurolite are again, on the whole, abundant. No older sedimentary rocks in Cornwall could have yielded them; to account for their presence, recourse must be had once more to the old Armorican land-mass.

The absence or rarity of garnets in the Pliocene, as in the other Tertiary and Cretaceous deposits of Devon and Cornwall, requires explanation, especially in view of their abundance in the Permian and Triassic rocks of Devon. Their absence may be due to one (or both) of two causes: (1) decomposition of the mineral

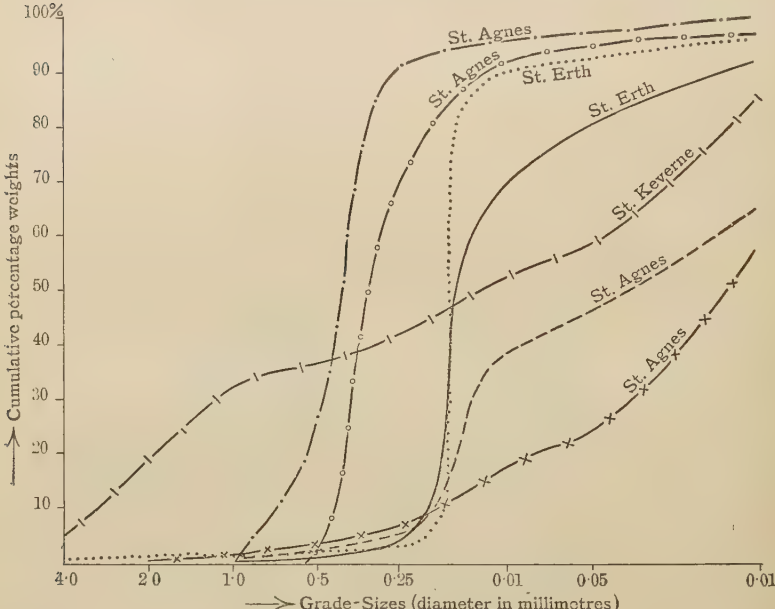
[1] 'The Geology of the Country near Newquay (Sheet 346)' Mem. Geol. Surv. 1906, p. 62.

[2] Q. J. G. S. vol. lxxviii (1922) pp. 348–77.

before or after deposition, and (2) derivation of the sediment from non-garnetiferous rocks. In the event of garnetiferous rocks occurring locally, a third explanation might be added—the submergence of such rocks beneath the waters in which the sediments in question were being laid down.

With regard to (1), if decomposition were the cause of absence or rarity, intermediate stages of partly-decomposed garnet should be found. However, such examples are notably absent, and the rare occurrences are those of clear fresh mineral fragments. Since rocks containing abundant garnets occur locally, we are left with

Fig. 7.—*Graphical representation of typical mechanical analyses of the Pliocene deposits.*



the alternatives, either that they were submerged, or that the detritus-bearing currents avoided them. In view of the fact that the Pliocene materials lying on the 400-foot platform are of shallow-water and even shore-line and wind-drifted character,[1] it is improbable that a subsidence of more than 500 feet below the present level took place. Such a subsidence would be even now insufficient by hundreds of feet to submerge the garnet-bearing metamorphic aureoles and granite-masses of, for example, Bodmin Moor or Dartmoor. Nor would a subsidence of 600 feet

[1] Many of the minerals are well-rounded at St. Erth, and especially so at St. Agnes.

(an amount actually too great, in view of the character of the St. Erth mollusca) submerge many areas of garnetiferous rocks. Moreover, it is only reasonable to suppose that in Pliocene times a greater area of the granite would have been covered by contact-rocks, for denudation had not then reduced the aureole to its present extent; and thus the area of garnetiferous rocks above sea-level would have been greater still. Consequently, the problem of the rarity or absence of garnets in the Cretaceous and Tertiary sediments of Devon and Cornwall remains unsolved.

(5) Deposits of Doubtful Age.

Gravel near Riddaford Water, Bovey.—In the course of discussing the results of the investigation detailed above, my attention was drawn by Mr. H. Dewey to a patch of gravel, lying about a quarter of a mile north of Riddaford Water, and east of the small valley.[1] A plateau-like area occurs here at about 400 to 430 feet above Ordnance-datum, and is of small extent, the feature not being so well-marked as in Cornwall. On the 1-inch Geological Survey map the area is coloured as Bovey Oligocene deposits, and is bounded on the west by metamorphosed Culm. Gravel-pits expose about 10 feet of brown and greyish gravelly sands. The pebbles include Culm chert, killas, and granite, but no prolonged search for other rocks was made.

Examination of the finer sandy constituents shows that the grey colour is due to enormous quantities of lustrous blue-black schorl, which is seen under the microscope to occur in grains of all sizes and tints. Beside zircon, rutile, and doubtful cassiterite, andalusite is abundant. The last-named mineral is dirty with numerous inclusions, possesses frayed edges, and displays faint pink pleochroism. Grains as much as 0·7 mm. in diameter occur. Chiastolite, with a well-marked cross, is also seen (fig. 6 *b*, p. 220). Magnetite occurs in small grains, 0·1 mm. in diameter, of irregular shape, and partly altered, usually to limonite, but sometimes to more hematitic material. Ilmenite is found in small amount in irregular grains about 0·5 mm. in diameter, the grains being mostly altered to limonite and leucoxene. Many kaolinized grains of calc-alkali felspars are found, but no alkali-felspar.

The mineral assemblage is thus purely local, requiring, however, the disintegration of aureole-rocks as well as granite for its accumulation. The occurrence of magnetite is noteworthy, although the mineral is not abundant.

Gravel from above Lustleigh Cleave.—Gravelly deposits occupy the bottom of a valley-like depression carved in the granite of Dartmoor above Lustleigh Cleave, and situated about 2½ miles

[1] H. Dewey, Q. J. G. S. vol. lxxii (1916–17) p. 63.

north-west of Lustleigh village. The deposits were described by Mr. H. J. Lowe [1] as evidence of river-capture since Eocene times; but his conclusions were not accepted by the officers of the Geological Survey when they resurveyed the area. The gravels occur at about 750 to 800 feet above Ordnance-datum, and have been turned over for stream-tin. The workings are now mainly overgrown. Pebbles of granite, elvan, schorl-rock, and vein-quartz were recorded.

Examination of the sandy matrix reveals an abundance of tourmaline- and zircon-grains (0·2 mm. in diameter and of good crystal form) together with a few grains of rutile, a single fragment of epidote, and a single grain of garnet. Kaolinized alkali-felspar and magnetite are abundant, in marked contrast to the occurrences at Riddaford. Ilmenite is exceedingly plentiful: angular grains of all sizes up to 0·5 mm. in longest diameter occur, a few of them displaying alteration to leucoxene. The abundance and freshness of ilmenite, the occurrence of magnetite, and the absence of aureole-minerals seem to indicate that only granitic débris has gone to make up the deposit.

IV. Comparison with other British Deposits of Similar Age.

Cretaceous.

The petrology of the Upper Greensand generally has not yet been investigated in detail, but Mr. G. Macdonald Davies has published notes on the petrology of the formation in Surrey.[2] The Haldon Greensand differs mainly from the Upper Greensand farther east in the abundance of its andalusite and topaz, minerals which would naturally break down to a greater or less extent during transport. I have traced both andalusite and topaz in the Upper Greensand of the Blackdown Hills, and as far east as Devizes. The limit of the eastward extension of these minerals has yet to be proved. The proportion of blue tourmaline in the more easterly deposits is much smaller than in the Haldon sands, but the brown variety is still abundant. Garnets occur much more frequently in the Upper Greensand of Surrey than in that of the West Country, yielding evidence, at any rate in part, of a different source of origin for the detritus. Staurolite does not seem to be so abundant in the eastern as in the western deposits. Kyanite, though always abundant in the Lower Greensand, has not been recorded in the Upper Greensand of Surrey. Over the Blackdown area, however, it is abundant, and occurs in larger grains than in the Haldon Cretaceous, where it is also less plentiful. The Blackdown Greensand would therefore appear to contain material brought by currents from the south-west or south-south-west, as well as those from the west-south-west.

[1] Geol. Mag. 1902, p. 397.
[2] Proc. & Trans. Croydon Nat. Hist. & Sci. Soc. 1915, p. 84.

Eocene.

The westernmost deposits of Upper Eocene age in the Hampshire Basin contain an assemblage of minerals not unlike that of the Eocene of Devon. Topaz is present, although not abundant (as, for instance, at Fordingbridge); it disappears as the deposits are traced eastwards. Andalusite becomes rare, but occasional grains are seen. Kyanite and staurolite increase in abundance, and occur in larger grains than those found in the Haldon sands. The presence of these two minerals is most simply explained by postulating a marine or fluviatile current from the south-west into the Hampshire Basin, the drainage there uniting with that from Devon which brought the abundant tourmaline into the sediments. Blue tourmaline becomes less abundant towards the east. Garnet is absent or very rare in the Dorset and Hampshire Eocene, just as it is in Devon.

Little doubt thus exists, on petrological grounds, that the Upper Eocene of Dorset and Hampshire was brought down by rivers draining both the West Country and an area of metamorphic rocks on the south-west which contained kyanite and staurolite. Clement Reid advocated a western origin for the Upper Eocene of Dorset, because of the abundance of kaolin and the character of the pebbles in the gravels.[1] In view of the greater variety of minerals in the Eocene deposits generally of the London Basin, it is clear that, while some may have been derived from the west and south-west, other areas must have been laid under contribution.

Oligocene.

The difference in character of the Devon deposits and the Oligocene strata of the Hampshire Basin is such that a comparison of the petrological characters of the two is hardly likely to show many points of similarity. Briefly (as noted on p. 220), it may be stated that the western deposits contain a more restricted assemblage of minerals. The Oligocene of the Isle of Wight resembles the Upper Eocene of the same area in its detrital minerals. The topaz and andalusite which occur rarely in the Bovey Basin have not been observed in Oligocene material from the eastern outcrop.

Pliocene.

The assemblage of minerals in the Cornish Pliocene, while far from being a poor one, is by no means so varied as that from the Boxstone Bed and various Crag deposits of East Anglia. Certain striking differences are to be noted. Large red garnets, for example, are among the most abundant and typical minerals in East Anglia. Green hornblende, pyroxene, biotite, epidote, chlorite, and other minerals are very abundant, but topaz is rare. The source of the staurolite, andalusite, kyanite, and tourmaline in

[1] Q. J. G. S. vol. lii (1896) p. 490.

Table of Mineral Occurrences.

	Greensand, Haldon.	*Eocene, Haldon.*	*(?) Eocene, Buckland Brewer.*	*Oligocene, Bovey Basin.*	*Oligocene, Petrockstow.*	*Pliocene, Cornwall.*	*Doubtful age, Riddaford.*	*Doubtful age, Lustleigh Cleave.*	*Doubtful age, Marazion.*
Garnet	1	1	1	1	—	1	—	1	7
Magnetite	—	—	—	—	—	6	3	7	2
Anatase	5	5	3	5	—	5	—	—	5
Cassiterite	2	2	1	5	—	4	1	—	2
Rutile	7	8	8	9	8	8	7	4	8
Zircon	8	9	9	9	9	9	9	9	8
Apatite	2	—	—	—	—	—	—	—	—
Corundum	1	3	—	—	—	1	—	—	1
Ilmenite	2	2	2	6	6	9	4	9	10
Limonite	10	10	10	10	10	10	10	10	10
Quartz	10	10	10	10	10	10	10	10	10
Tourmaline (blue & brown)	9	9	9	9	9	9	9	9	10
Andalusite	8	7	7	3	1	9	8	—	9
Brookite	5	—	—	2	—	5	—	—	—
Chiastolite*	—	—	—	4	—	—	4	—	—
Sillimanite	—	—	—	—	—	—	—	—	2
Staurolite	9	4	1	3	3	8	—	—	5
Topaz	6	9	7	2	3	8	—	—	5
Chlorite	—	1	—	—	1	1	—	—	—
Epidote	—	1	2	1	1	3	—	1	8
Glauconite	9	3	—	3	3	7	—	—	3
Hornblende	—	1	—	1	1	—	—	—	5
Monazite †	—	—	2	2	—	?	—	—	—
Muscovite	9	6	5	8	5	9	—	—	10
Orthoclase	—	2	—	3	—	2	—	10	2
Phlogopite	—	—	—	—	—	2	—	—	—
Serpentine	—	—	—	—	—	3	—	—	9
Kyanite	7	2	1	—	—	9‡	—	—	8
Oligoclase	3	4	3	5	7	6	7	7	7
Chert	10	10	10	10	5	10	10	—	10
Flint	—	10	10	10	—	—	—	—	10

* Grains showing a well-developed black cross.
† Confirmed spectroscopically.
‡ Absent at Crouza Down, Lizard.

The indication of relative abundance by means of numbers seems first to have been introduced by E. Artini,[1] whose scale ran from 1=very abundant to 10=very rare. Later, F. Salmojraghi[2] reversed the order, and used the following scheme: 1=exceedingly rare; 2=rare; 3=very scarce; 4=scarce; 5=frequent; 6=very frequent; 7=abundant; 8=very abundant; 9=dominant; 10=ultradominant. This scheme, which is similar to that devised recently (and independently) by Prof. W. W. Watts, is used in the above table.

[1] Riv. di Min. & Crist. Ital. vol. xix (1898) pp. 33–94.
[2] Rendic. Ist. Lomb. Sci. Lett. vol. xl (1907) pp. 870–87.

the eastern deposits is doubtless on the south-east, namely, the metamorphosed Palæozoic rocks of the Southern Ardennes. It is noteworthy that the Pliocene of Belgium resembles generally that of East Anglia in its petrography.

The case of the Lower Pliocene outliers on the North Downs at Lenham, Netley Heath, Newlands Corner, etc., is, however, different.[1] The mineral assemblage of these deposits is more varied than that of the Cornish Pliocene; but in one important respect, namely, that of the great rarity of garnets, the two series of deposits resemble one another.

V. Summary of Conclusions.

The main conclusions to be drawn are as follows:—

General.

(1) The Cretaceous and Tertiary outliers of Devon and Cornwall are linked broadly one with the other on petrological grounds.

(2) Their mineral assemblages differ radically from those of the Permian, Trias, or Lias-Inferior Oolite of the West of England, in that they contain more material derived from British and less from 'Armorican' rocks.

(3) On the whole, the deposits are moderately-well graded. Certain of the Pliocene sands form exceptions to this rule. Many of the Cretaceous deposits are poorly graded, and many of the Eocene badly. Greater differentiation has taken place in the Oligocene and Pliocene deposits. These lithological variations throw light on the mode of origin of the various deposits, as indicated below.

(4) Tourmaline, in grains of all sizes, shapes, and colours is by far the most abundant mineral throughout. It is obviously derived from the granite-masses and their aureoles.

(5) Andalusite and topaz may, in addition to tourmaline, be regarded as the characteristic minerals; they are of local origin.

(6) Garnet is rare or absent in all the deposits, despite its abundance in the igneous and metamorphic rocks of Devon, Cornwall, and Britanny, and in the Permian, Triassic, and Lias-Inferior Oolite of Devon and Dorset.

(7) Kyanite and staurolite occur plentifully in the Cretaceous and Pliocene deposits, their source probably lying in the old Armorican land-mass which was situated on the south-west.

(8) As the Upper Greensand and Upper Eocene deposits are traced eastwards, topaz and andalusite occur in decreasing quantity.

[1] See G. Macdonald Davies, *op. cit.* p. 82; also Proc. Geol. Assoc. vol. xxviii (1917) p. 49.

Cretaceous.

(9) The Upper Greensand deposits are marine and glauconitic. Their mechanical composition indicates that they were deposited near land, and were in course of being sorted, but the process had not been completed. In view of the occurrence of abundant small, clear, andalusite-grains, and much kaolin and tourmaline (but very little chiastolite), their origin may be sought in Cornwall rather than in Dartmoor. The deposits offer no evidence that the Dartmoor granite had been exposed by denudation. Rivers and currents brought heavy minerals, such as kyanite and staurolite, into the Cretaceous basin from the south-west.

Eocene.

(10) The Eocene deposits represent the breaking down of an enormous quantity of Chalk, as well as of much Cretaceous and granitic material and of aureolar rocks and minerals. They are more clayey in character and more poorly graded than the Cretaceous deposits. The mechanical composition and colour-mottling support the view that they are river-deposits. The abundance, angularity and large size of the topaz, and the frequent occurrence of dusky andalusite, point to a source of origin not far distant, such as might be provided by the Dartmoor granite. The abundance of the topaz, a vein and marginal mineral belonging to a late stage of crystallization of the granitic magma, suggests that the Dartmoor intrusion was being newly exposed. The Greensand was also laid under contribution, but there is no evidence that far-travelled minerals arrived directly in the Eocene deposits. The drainage-area that yielded the sediments was much more restricted than in Cretaceous times.

The petrography of the Marazion deposits provides no clue to their age. The constituents of the outlier near Buckland Brewer are similar to those of the Haldon Eocene. The presence of flints links the two deposits, and is in contrast with its absence in the Pliocene deposits of Cornwall.

Oligocene.

(11) The restriction of drainage-area noted in the Eocene was maintained in the Oligocene, resulting in two isolated lake-basins in North and South Devon respectively. The petrographical character of the rocks in both basins is similar, the deposits being poorly graded and obviously a result of the sudden arrest of streams of detritus-laden water, bearing clayey and coarser material from Dartmoor. The minerals are all of local origin, and the presence of chiastolite (characteristic of the aureole) is noteworthy.

Pliocene.

(12) The Pliocene deposits, like the Cretaceous, are marine and glauconitic. From their position and petrographic characters they indicate a widespread submergence of the Oligocene land-area. For the greater part, the detritus is moderately well-sorted, and derived from a wider area than any of the other Tertiary deposits. The assemblage of heavy detrital minerals is abundant, varied, and polygenetic.

For fruitful discussion of several of the matters dealt with in this paper I desire to express my thanks to Mr. Henry Dewey. For critically reading the manuscript, and for the preparation of much material in the laboratory, I gratefully acknowledge the assistance of Mr. J. G. A. Skerl.

Discussion.

Mr. H. B. Milner drew attention to the deposits at Orleigh Court (near Bideford) which the Author had described as Eocene (?). He (the speaker) had examined the mineral residues from this deposit, and was impressed by their strong resemblance to the Pliocene beds of Cornwall. The Orleigh-Court material presented the same andalusite, topaz, kyanite, and typical flat tourmaline-grains, among others, as those met with in the Cornish deposits; and, on account of this, and the fact that the situation of the Orleigh-Court outlier was in accordance with the theory of pre-Pliocene drainage previously advanced by him, he was more inclined to regard the material as being of Pliocene age.

With regard to the Author's remarks on ilmenite and magnetite, the speaker agreed as to the general rarity of the latter in sediments, both in this country and in the alluvial deposits of Ceylon, Brazil, and West Africa. A criterion of differentiation between the two species was a crimson, combined with a dull metallic lustre (seen with strong incident light) in the case of ilmenite, and the adamantine silvery-grey lustre reflected from highly-facetted grains (like 'pin-points') in the case of magnetite.

He also drew attention to the Author's mode of recording the results of petrographic examination of samples, and urged the general adoption of Prof. Watts's suggestion that numbers should be used to replace letters; comparison of numbers—by the mental picture conveyed—was of far greater help in assessing the frequency of species, especially where the correlation of many samples had to be undertaken.

Prof. W. W. Watts referred to the fragments in the Teignmouth Permian breccias, and enquired whether the evidence given by them was in agreement with the Author's view as to the late exposure of the Dartmoor granite-mass. He also wished to know whether the Author agreed with Mr. Clement Reid's attribution

of the Bovey deposits to the Aquitanian division of the Miocene. He was interested to hear that the deposit at Petrockstow could be correlated with the Bovey Beds.

The Author, in reply, emphasized the fact that, so far as correlation of deposits was concerned, the study of the petrology would supplement, but in no way replace, the use of fossils.

In reply to Prof. Watts, he expressed the opinion that, in view of the general character of the petrology of the Permian deposits of Devon, the coarser constituents were probably derived from the apophyses of the earlier-exposed Cornish granite-masses rather than from Dartmoor.

The small outlier of Tertiary deposits of Buckland Brewer seemed to the Author at present to bear a closer resemblance to the Eocene deposits of Devon than to the Cornish Pliocene, and he felt that it would be equally as difficult (if not more so) to fit them into Pliocene as into Eocene geography.

[July 6th, 1923.]

10. *The* EARTHQUAKE *of 7th* AUGUST, 1895, *in* NORTHERN ITALY. By RICHARD DIXON OLDHAM, F.R.S., F.G.S. (Read November 8th, 1922.)

ON the 7th of August, 1895, an earthquake was felt over the greater part of Lombardy and Tuscany, and in the Alpine districts of Northern Italy. Although only a feeble shock, nowhere exceeding an intensity of IV° Mercalli, it is worthy of attention as being of unusual type, and affording an illustration of some general principles which have been deduced from the comparative study of a large number of earthquakes. The details of observations recorded are published in vol. i. of the 'Bollettino della Società Sismologica Italiana'; on pp. 162-67 reports from 81 distinct localities are given, mostly with little more information than a mere record of an earthquake, but a certain number contain fuller details. These localities are plotted on the map accompanying this paper (p. 232), which also gives an epitome of the pertinent facts recorded.

The time, as shown by continuous-record seismographs, was about 20h. 50m., mid-European time; the area, over which there is a practically continuous series of records, is approximately triangular, the sides being about 160 miles in length, making the seismic area about 15,000 square miles, and possibly about 20,000, if the shock is included, which was felt, at about the same time, at several places in the Island of Elba. The report, from Portoferraio, is attributed without question to the same earthquake, but it may have been an independent shock, approximately coincident in time with the larger one. In favour of this supposition may be placed the fact that the nearest locality on the mainland from which record was received is over 50 miles from Portoferraio, and that the shock was apparently not sensible, but only instrumentally recorded, at Siena, which is considerably nearer the boundary of the region covered by fairly continuous records. Against the supposition may be placed the fact that the authorities concerned in the preparation of the published accounts, who had the original reports before them, had no hesitation in regarding the reports from Elba as referring to the same earthquake as those from Tuscany. In presence of this doubt, the Elban reports will be left out of consideration: if included, they would only strengthen, and if excluded, would not invalidate, the conclusions illustrated by the other records.

An attempt was made to determine the degree of intensity, according to the Mercalli scale used in Italy, at each locality; but in the greater proportion of cases the information was too scanty to allow of this being done. In those cases where a degree could be assigned with some certainty, it is indicated on the map (p. 232), and a consideration of these shows that there was no

Sketch-map illustrating observations of the earthquake in Northern Italy of 7th August, 1895.

defined centre of maximum intensity, round which isoseists can be drawn at increasing distances. Such a centre might possibly be recognized at Sestola (44° 14′ lat. N., 10° 45′ long. E.), where the fall of small fragments of plaster is recorded; this might bring it into the V° Mercalli, but only very doubtfully. Against the recognition of a centre of maximum intensity, where the shock would be severe enough to attract general attention, must be put the fact that it is especially recorded that the shock was not felt at the observatory on Monte Cimone. This observatory lies about 5 miles from Sestola and in a straight line between that place and Fiumalbo (44° 11′ lat. N., 10° 39′ long. E.), which lies about 2 miles farther on, and at which the intensity was about the same as at Sestola. Taking the other localities, it is found that at nearly all a distinctly lower intensity is indicated; but scattered among them are places where the reports would indicate at least IV°, and some of these are on the extreme limits of the area covered by the reports. At Ala (45° 41′ lat. N., 11° 0′ long. E.) and Valli di Signori (45° 44′ lat. N., 11° 15′ long. E.) on the north, at Rettinella (45° 3′ lat. N., 12° 9′ long. E.) on the east, and at Pontedera (43° 40′ lat. N., 10° 38′ long. E.) on the south, all localities from beyond which no reports were received, an intensity of not less than IV° is indicated, though to other places nearer the centre of the seismic area a greater intensity than II° or III° M. cannot be assigned.

The sound phenomenon gives no better indication of a distinct epicentral area, for, although reports are more numerous in the region between Florence, Bologna, and Carrara, the sound was recorded at scattered places up to the extreme limits of the seismic area, as at Erba (45° 48′ lat. N., 9° 13′ long. E.), Valli di Signori, Argenta (44° 36′ lat. N., 11° 50′ long. E.), Rotta (43° 39′ lat. N., 10° 41′ long. E.), and Lari (43° 34′ lat. N., 10° 35′ long. E.).

The presence of a noticeable vertical component of the motion (sussultorio) is generally confined to the central area, but the attempt to make use of this proved as little conclusive as the distribution of intensity and sound, for the vertical movement was reported from localities at the extreme limits of the seismic area, as at Erba, Castelletto di Brenzona (45° 41′ lat. N., 10° 45′ long. E.), Argenta, and Lari.

The close clustering of reports from the southern portion of this area, lying in the region west of Florence and Bologna, is suggestive of an epicentral area of greater intensity of shocks; but this might well be attributed to the fact that this is a region of comparative wealth and ancient culture, where earthquakes have long been a subject of study, and where the number of potential observers and recorders would be greater than in the region on the north, from which no reports were received, until we come to the southern edge of the Alps. It may be that the peculiar distribution of the reports, and the absence of any records from

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considerable areas, on either side of which the shock was recorded, is real, and directly connected with the origin of the shock: this point will be referred to later on, but, meanwhile, it must be noted that the distribution of the reports is so much in accord with the probable distribution of potential recorders, that no great importance can be attached to the absence of records from certain regions within the boundary drawn through the extreme localities at which the shock was recorded.

It is, consequently, apparent that none of the methods ordinarily employed allows of the fixing of a definite epicentre, or the drawing of successive isoseismals of decreasing intensity. To a great extent this is due to the peculiar nature of the shock, quite different in character from that usually noticed in moderate earthquakes, for which the customary scales of intensity are framed; it was much more akin to the movement which is noticed on the borders of the seismic area of a great earthquake, when the movement, as it is propagated, dies out in comparatively slow undulations, often more noticeable through the effect produced by tilting than by actual sensation. At all the places where this earthquake was recorded, an undulatory character was noticed, suspended objects were set swinging, doors and windows were shaken or moved. At Sestola it was especially recorded that there was a sensible inclination of walls, giving to persons standing at a window the impression of danger of falling out, and at some of the localities the earthquake was only recognized by a vibration of doors or windows. These are all features characteristic of the marginal portion of the seismic area of a great earthquake, and to these the ordinary scales of intensity are not applicable, for some of the results are such as would only be produced by a considerable earthquake of the more common type, where the rattling and swinging are set up by inertia, instead of by inclination of the surface, due to the passage of the long waves propagated outwards from a great disturbance. It is not unnatural to attribute the similarity of the movement, noticed in this earthquake, to a similar cause, and, if this be so, the only direction in which distance can be attained is downwards into the interior of the earth —in other words, we are not dealing with a small disturbance of shallow depth, but with the marginal area of a greater disturbance, diminished in intensity by propagation before it reached the outer surface.

In attempting to estimate the depth at which this origin lay, recourse was first made to the instrumental records, but no help was found in that quarter. The records from within or just outside the areas over which the shock was sensible, agree in fixing the time at about 20h. 49·7m. M.E.T., but there is no regularity or evident connexion between distance from the centre of the shocks and the time of record, and the variations extend from 49m. 20s. to 50m. 20s. omitting those which merely give the time to the nearest minute. Outside the seismic area the shock was recorded

only at Rome, where the time (20h. 51m. 10s.) is in accord with the supposition that the record was due to the arrival of the surface-waves. In 1895 the number of instruments capable of recording distant earthquakes was few, and none of them recorded this earthquake, which may be accounted for by the fact that at Rome, about 100 miles from the outer edge of the seismic area, there was only a slight thickening of the record on the two most sensitive of the instruments in action. Had this earthquake occurred some years later it is probable that more records, and possibly more distant records, would have been obtained from the more numerous, and more sensitive, instruments then installed; but the Rome record is of interest, as showing that the disturbance was one of the type which gives rise to long-distance records.

There remain, then, the descriptive records, on which to base an estimate of depth of origin, and, in making use of these, the first difficulty encountered is the explanation of the peculiar distribution of the records. One possible hypothesis is, as has been stated, that there was in reality a large area of tolerably uniform intensity of shock, and that the irregular distribution of the records is due to the presence or absence of potential observers. In this case we are dealing with a shock due to the propagation of wave-motion directly from the bathyseism, and this wave-motion, as revealed by the records, was of twofold character: there was first the undulatory movement, only noticed through the effect of the inclination of the surface produced by it, and also a vibratory movement of greater rapidity, giving rise to the sound phenomenon and to tremors which were everywhere of feeble intensity. The actual amount of the acceleration was everywhere small, but the reports do not admit of the formulation of any precise estimate of the variation: at the outside it may have been twice as great in the central part of the seismic area as in the marginal regions. The rate of variation of acceleration of the wave-particle with distance from the origin has not been investigated; but, if it be taken as inversely proportional to the distance from the origin, the depth would come out as something near 50 miles; while, if the variation is inversely proportional to the square of the distance, the depth might reach double this figure.

This is not, however, the only possible interpretation of the records, for it may be that the intervening gaps, from which the earthquake was not reported, represent a real absence of noticeable shocks, that the immediate origin of the earthquake was a series of fractures, of comparatively shallow depth, and that the distribution of the records represents, at least approximately, the extent of the sensible shock. In some ways, this interpretation is in accord with the peculiar distribution of the records and the absence of any defined area of maximum intensity. The records lie mostly along a line running about north-eastwards from Pisa, and along another running eastwards from Como, the two lines meeting in the district north-west of Venice; there is also indication, less

well marked, of another line joining the extremities of these two, and running from near Como towards Pisa. If the origin of the earthquake really was of the nature of two, possibly three, fractures or series of fractures, it is not conceivable that they could have been due to any cause directly connected with the tectonics of the surface-rocks: for, with the exception of the east-to-west northern line, they run across the structural features as seen on the surface. But it is conceivable that, if any general change of bulk had taken place in the material underlying that portion of the crust over which the earthquake was felt, it might be the determining factor in producing fractures in the crust, which would be unconnected with the surface tectonics, and in this way the isolated area in Elba, where an earthquake was noticed in various parts of the island, could be brought into relation with the main area in a manner not otherwise easy to explain. This change of bulk might be of equal area with the earthquake, in which case it need not lie at a great depth from the surface, but so large an area of almost uniform change is not easy to understand; it becomes more intelligible if we consider the original change of bulk to be of more restricted dimensions, and the effect, immediately below the solid crust, to be the transmitted effect of such change. This transmission would not be merely vertically upwards, but would spread outwards at a certain angle which might be as much as 45°, and in this case the ultimate origin would lie at a depth of the order of 120 miles if the dimensions were inconsiderable; but, if considerable, the depth would be proportionately diminished, and thus for an origin having one-quarter of the dimensions of the earthquake it would become about 90 miles, and 60 miles for one-half the dimensions. On the other hand, the angle of spreading of the effect would probably not be as much as 45°, and, if only 30° (corresponding to an apical angle of 60°), the depths would be nearly one and three-quarters as great as those mentioned.

From these facts and considerations it will be seen that no very positive conclusions can be drawn, nor any precise estimate made, of the depth of origin; this much, however, is clear, that the earthquake was more akin to those which give good distant records, than to the ordinary type of local earthquake; and that the depth of the ultimate origin of the shocks was great, probably of the order of about 100 miles or so, below the outer surface of the earth. This conclusion is of interest in its accordance with the deductions, recently announced by Prof. H. H. Turner, that the origins of many of the disturbances, which give rise to good long-distance records, lie at a depth of about 200 kilometres (125 miles).

11. *The* PAMIR EARTHQUAKE *of* 18*th* FEBRUARY, 1911. By RICHARD DIXON OLDHAM, F.R.S., F.G.S. (Read November 8th, 1922.)

THE Pamir earthquake of the 18th of February 1911, though of destructive violence in the central region and giving rise to long-distance records, would probably have passed without special notice had it not been for two circumstances: one, that it was accompanied by a landslip of exceptional dimensions, which dammed one of the principal drainage-valleys of the region, and gave rise to a permanent lake over 15 miles in length and 900 feet in depth; the other, that the late Prince Boris Galitzin formulated the conclusion that this landslip was the originating cause of the earthquake, and that this was an interesting and unique instance of coincidence of epicentre and hypocentre. Attention has been recently drawn [1] once more to this earthquake, and, although mistakes in Prince Galitzin's mathematical methods have been pointed out, the justice of his conclusion has been maintained; but this conclusion is so contrary to all other present knowledge of the character and behaviour of earthquakes, that a fuller examination of the evidence seemed desirable, and as this is not generally available, being published almost exclusively in the Russian language, it has seemed desirable to record the facts, so far as they are available.

Before dealing with the local observations and records of the earthquake, it will be well to refer briefly to Prince Galitzin's paper.[2] His conclusions were based primarily on the survey conducted in 1913 by Col. Spilko, from which it was computed that the mass of the landslip amounted to between 7 and 10 milliards of metric tons, and the height of fall was somewhere between 300 and 600 metres, from which it results that the amount of work done in falling, and set free by arrest of fall, lay between the limits of $2{\cdot}1 \times 10^{23}$ and $6{\cdot}0 \times 10^{23}$ ergs.

The next step was to estimate, from the seismographic records at Pulkovo, the amount of work transmitted past that station, and from this to compute what should have been the amount set free at the origin. The result of his computation gave $4{\cdot}3 \times 10^{23}$ ergs, a figure almost identical with the mean probable value obtained from the survey of the landslip, and hence it was concluded that the landslip gave rise to the earthquake.

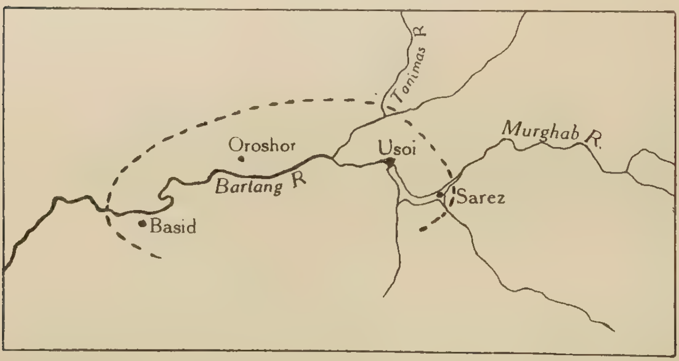
The whole calculation, however, is vitiated by the fact that, in

[1] At a geophysical discussion held in the rooms of the Royal Astronomical Society on March 3rd, 1922. [See also H. Jeffreys, 'The Pamir Earthquake of 1911, February 18, in relation to the Depths of Earthquake Foci' Monthly Notices, Roy. Astronom. Soc. Geophys. Suppl. vol. i (1923) pp. 22–31.]

[2] 'Sur le Tremblement de Terre du 18 février 1911' C. R. Acad. Sci. Paris, vol. clx (1915) pp. 810–14.

computing the amount of work transmitted past Pulkovo, the departure of the seismogram from the mean position was attributed to a horizontal movement of the ground, the seismograph being taken to act as a steady point; but it is well established that the record in the third phase (or long) waves, which were exclusively used in forming the estimate, is due to tilting and not to inertia: consequently the estimate, being based on an erroneous interpretation, is necessarily in error, and the real value at Pulkovo must be in defect of the adopted value to an unknown, and probably considerable, extent. Besides this, some faults have been pointed out in the formula used for computation. These considerations undermine the basis on which Prince Galitzin's conclusion was founded, and, in addition, it may be urged that, in the present very imperfect state of our knowledge of the nature and physics of

Sketch-map of the epicentral area of the Pamir earthquake of 18th February, 1911.



these surface-waves, no final conclusions can be drawn from the most exact agreement, nor from the absence of such agreement, between computation and observation. It becomes necessary, therefore, to examine the question from other aspects before accepting, or rejecting, the assertion that the landslip was determined by the earthquake.

The only account of this shock, that I have been able to find, is a report by Col. Spilko, published by the Russian Imperial Geographical Society in 1914.[1] He was primarily concerned in

[1] 'The Pamir Earthquake of 1911 & its Consequences: Chronological Reference & Report of the Works of the Military Detachment of the Pamir' by Col. Spilko, Staff Officer & Chief of the Pamir Detachment, Bull. Soc. Imp. Russ. Géogr. vol. 1 (1914) pp. 68–94, with map & plate of sections (in Russian). On account of the interest attaching to this earthquake, I have had a translation made of Col. Spilko's paper, and deposited it in the Library of the Geological Society of London, for the use of those who may be interested in the subject.

the examination of the great landslip and the lake produced by it, but incidentally gives a general account of the earthquake derived from official and other reports; reference is made to accounts and reports in newspapers, but all that is important, for the present purpose, seems to have been incorporated by him.

The earthquake took place on the night of the 5th–6th February, 1911 (O.S.), the time, as locally determined, varying from 11.15 p.m. to 1.20 a.m.[1] The central region lay close to the junction of the Tanimas with the Murghab, or Bartang, river, in about lat. 38° 15′ N., long. 72° 38′ E., and here the destruction, not only of villages but of roads, bridges, and all means of communication, was so complete that nearly six weeks had passed before news could reach either the military headquarters at the Pamir Post, or the civil headquarters at Khorog. Two attempts to reach the devastated region were made: Capt. Zaimkin was despatched down the Murghab valley, and at Sarez found further progress impossible; while, from the Oxus valley, the official despatched by the Governor of Roshan found his progress towards Oroshor, the headquarters of the district, stopped by complete destruction of the roadway, at some place unspecified, before he could reach his destination. According to Col. Spilko's account, written two years later, the total loss of life amounted to 302 men, women, and children; details are given of separate villages and settlements, some of which I have been unable to find on any map; but the easternmost of those that I have been able to identify is Sarez, which escaped rather lightly with a loss of some houses and no deaths, and the westernmost Basid, which was almost completely destroyed. The distance between these two places is about 35 miles in a direct line; but the region over which the earthquake reached a destructive degree of violence evidently exceeded this limit, for it is recorded that the first news of the disaster that reached the Oxus valley was brought by a plucky Tajik, a resident of Basid, who descended the Bartang in a native boat (probably an inflated skin), and from this account it is evident that the destruction of the roadway and interruption of all land communication extended for some distance westwards, or downstream, from Basid. In this region, besides the destruction of buildings, of bridges, and of the galleries by which the roads were carried round the faces of cliffs, caused by the direction of the earthquake, there were numerous landslips, which will be dealt with later.

In an easterly direction the earthquake was strongly felt at the Pamir Post, where it is said to have lasted two minutes, accompanied by a subterranean rumbling, was severe enough to make all the inhabitants leave their houses, and caused clocks to stop. A second shock an hour later is reported. Some cracks were formed in buildings. At Kizil Robat the shock was felt in about the same degree, and at Rangkul and Tashkurgan (in Chinese

[1] The time, as determined from distant records, would be about 18h. 41m. Greenwich mean time, or 23h. 31m. local time.

Turkestan) it was noticed, as a slight undulation, only by a few people.

In a northerly direction it is reported that the waters of the Kara-Kul Lake surged over the eastern, low-lying, bank for a distance of about half a verst (1750 feet) leaving a bank of ice behind on their retirement. In the Alai district it was feebly felt, in about the same degree as at Tashkurgan.

Westwards the shock was severe, and caused great alarm throughout the districts of Shignan and Roshan. At Khorog a subterranean rumbling was noticed, great alarm was caused, but no damage reported. At Ishkashim the earthquake was severe, and followed at intervals by feebler ones. No damage to buildings was done.

The seismic area of this shock must have extended into Afghan territory, across the Oxus, but no records on which any reliance can be placed are available. Col. Spilko quotes reports that 300 houses were destroyed and 460 people killed in Kabul, 60 houses and 240 deaths at Kala-i-Yavun, 70 houses and 2 deaths at Konabad, and a few houses (but no deaths) at Faisabad. The first-named of these, unless some place which I cannot identify is meant, obviously cannot refer to this earthquake. The other reports, if accepted, must refer to a different earthquake, or else indicate that this, like some of the Calabrian shocks, had two distinct centres of greatest intensity; more probably, however, the reports are either greatly exaggerated, or wholly imaginary.

These accounts allow of the formation of an approximate estimate of the magnitude of the earthquake. The centre of greatest intensity lay not far from Oroshor, the headquarters of the district of the same name, or between it and the junction of the Tanimas aud Murghab valleys. The central area, over which the intensity was at least VIII° R.F.,[1] extended from about Sarez on the east to beyond Basid on the west, the dimension in this direction being at least 40 miles; in the transverse direction the dimension is indeterminable, as population and communications are confined to the valleys. The outer limit of the area over which the shock was at all sensible can be fairly well fixed in an easterly direction at about 150 miles from the centre; in a southerly direction the limit was probably about the same; on the west the distance would be about 220 miles from the centre, if the earthquake was really felt at Konabad (Khanabad). As has been pointed out, however, all the reports from Afghan territory are very uncertain, and the authentic records suggest that the limit in this direction was less than on the east, possibly not more than 100 miles; on the north the limit seems to have been much the same, or about 100 miles. The actual dimensions of the region included by the II° R.F. isoseist may be put at about 250 square

[1] Col. Spilko gives the intensity as VIII° over the whole of this region; but the accounts reproduced by him and the description by Sir Aurel Stein (quoted later) show that over the greater part of it the intensity must have ranged higher, and reached at least X°.

miles, and those of the area included by the VIII° isoseist being about 40, the ratio between the two is about 6 to 1. The corresponding ratio in the case of other destructive earthquakes works out at various values, between the extremes of 12 to 1 and 3 to 1, the usual value being about 5 or 6 to 1. In this respect, therefore, the earthquake shows no abnormality, and there is nothing to suggest a radical difference in origin from other earthquakes.

Another feature which marks this earthquake as of the usual type and origin, is the occurrence of aftershocks. From the central region we have no certain records, but, both at the Pamir Post and Iskashim, subsequent shocks are definitely reported. Great earthquakes vary extremely in the number of aftershocks and the duration of the period covered by them; in some cases the aftershocks are few and soon over, in others they are numerous and prolonged, and there is no definite relation between the magnitude of the earthquake and the number of aftershocks. In a general way, however, the greater earthquakes are followed by more numerous aftershocks than the smaller, and the Pamir one of February 1911, though it must be classed with the great world-shaking earthquakes, was, in reality, a small one of its class. To this must be added that the nature of the country and its inhabitants precludes the possibility of anything like a complete record being obtained. The published reports are sufficient to show that there were at least some aftershocks, and that in this respect the earthquake was of normal type.

So far nothing has been said of the landslips, these having been reserved for separate consideration. Of the largest of them we have fairly full particulars, in the description and survey made by Col. Spilko's expedition. This slip fell from the mountains north of the Murghab valley, just above the village of Usoi (Usaid of the Indian Survey maps), which was overwhelmed and all the inhabitants destroyed, except two, who were away on the night of the earthquake. The débris of the slip formed a heap in the valley, measuring about 19,000 feet in length along the bed of the valley, about 12,500 feet in width across the valley, and very little short of 2500 feet in maximum depth, the total bulk being about 100,000,000,000 cubic feet, and the weight about 7,500,000,000 tons. These figures are necessarily approximate, as it is not possible to determine, from the map, the exact limit of the slip, nor is the original contour of the ground known. The barrier, formed by the slip, gave rise to a lake which, at the time of Col. Spilko's survey, had attained a length of 26 versts (about 17 miles) and a maximum depth of 131 sashin (917 feet); at the time of his visit the water-level was still rising, but this was probably seasonal, for two years later Sir Aurel Stein, traversing the same route, estimated the length at 15 miles. As the upper end of the lake was very narrow, merely a flooded river-channel, when surveyed by Col. Spilko, widely differing estimates of length might easily have been made by different observers;

moreover, the narrow part would be rapidly filled up by river-deposits, so that the estimate of the later observer is in substantial agreement with the survey of the earlier, and the permanent length of the lake may be placed at about 15 miles.

The landslip itself was of the ordinary type of mountain-slip; it was a downward rush of a mass of débris, moving more as a fluid mass than as either a slide, or a fall, of separate fragments, carrying on its surface, and embedded in it, huge unbroken masses of rock measuring hundreds of cubic feet in bulk. Where this moving mass impinged on the opposite side of the valley its momentum was checked, the upper surface surged up and, not having sufficient fluidity to return, was left banked against the hillside, forming a barrier across two minor tributaries from the south, in one of which a small lakelet was formed. This much is evident from Col. Spilko's survey and description, from which it is also evident that the great slip at Usoi was by no means the only one formed at the time of the earthquake. Upstream, his survey shows several smaller landslips in the direction of Sarez, probably those that blocked Capt. Zaimkin's progress in April 1911; and, even from the accounts collected by Col. Spilko, it is sufficiently evident that there must have been numerous others farther down the valley, in the districts which were not visited by him. The information, however, would have been very scanty but for the fact that, about two years later, Sir Aurel Stein travelled down the Tanimas valley to its junction with the Murghab, and then up that valley past the great slip and the lake of Sarez, and his graphic description [1] of the condition of the country, four years after the earthquake and landslip, throws much light on what would otherwise have been obscure and doubtful.

He states that already in the Tanimas valley he had come upon huge masses of débris, which had fallen from the slopes of the flanking spurs, and spread for several miles across the open valley-bottom. On turning up the Murghab valley, progress in its narrow gorge proved very trying, owing to the results of the earthquake, which had transformed the surface of the mountain-region in a striking fashion. In these defiles huge landslides had choked up, in many places, the whole river-passage, and destroyed the tracks. The big river, once rivalling in volume the Ab-i-Panja, had altogether ceased to flow, and strings of alpine tarns had replaced it. It took three days' hard travelling, along the steep spurs and over vast slopes of débris, to get to the point, near the mouth of the Shedau lateral valley, where the fall of a whole mountain had completely blocked the river, and converted the Sarez Pamir into a lake more than 15 miles long, still spreading up the valley. Enormous masses of rock had been pushed, by the impetus of the landslip, up the steep spurs flanking the Shedau valley,

[1] 'A Third Journey of Exploration in Central Asia, 1913–16' Geogr. Journ. vol. xlviii, 1916. The passages referred to in the text above are on pp. 214 *et seqq.*

forming a huge barrage which seemed to rise 1200 feet above the level of the lake.

Some idea of the difficulty of this journey may be formed from the fact that the distance, which it took three days to cover, is less than 15 miles; while the same distance, above the barrier, was covered in one day, although the going was still bad and only practicable on foot, and by men accustomed to mountain-climbing.

The foregoing account shows that the great landslip of Usoi was not the only one that accompanied this earthquake; it was by far the largest, but there were innumerable others, many of which can only be regarded as small in comparison with the exceptionally large one, and the accounts reproduced by Col. Spilko show that, besides those seen by Sir Aurel Stein, landslips occurred, on a similar scale, at least as far downstream from the junction of the Tanimas and Murghab. In part, this extensive development of landslips must be ascribed to the unstable, or semistable, condition of the steep slopes on each side of the deep-cut valley through a lofty mountain-region. Landslips, in fact, are by no means unknown in this region, and Colonel Spilko quotes, and accepts, the statement that the Yashil Kul, in the Ghunt valley (south of the Murghab), was caused by an ancient landslip of great size; yet the simultaneous occurrence of so many landslips over so large an area, as took place on the night of the 18th of February 1911, requires some common determining cause, which is to be found in the severe earthquake, known to have coincided with the fall of these landslips.

There remains, however, the possibility that the great slip at Usoi might have been the primary cause of the earthquake, and so of the other landslips. This supposition is negatived by the fact that the great slip is not situated at, or near, the centre, but on the extreme limit of the region of greatest destruction. The time of occurrence of a landslip may be determined by an earthquake, but the magnitude is very little influenced by it; in the case of those landslips, which can only be regarded as small when compared with the unusual magnitude of the Usoi slip, it may be taken as certain that slips were in preparation, and that sooner or later they would have fallen in very much the same magnitude, a magnitude determined by those initial cracks with which such mountain-slips commence. Even the great Usoi slip had probably been in preparation, in the same way, and would have come down in due course of time; its size, therefore, does not indicate a greater violence of earthquake. The position of the Usoi slip is, consequently, quite consistent with the conclusion that it, and all the other effects, were due to the earthquake as a common cause: it is not consistent with the supposition that the slip was the cause of the earthquake.

Besides the particular argument from the position of the Usoi landslip, with regard to the area over which the earthquake

reached a destructive degree of violence, there are some general considerations pointing to the same conclusion. It is known that in some cases earthquakes, of great violence in the central area, were only sensible for a comparatively short distance from it. The classic instance of this last-named type is the Ischian earthquake of 1883, which levelled Casamicciola with the ground, and caused 1800 deaths in that town alone, but was only felt by a few persons at Naples, not more than 20 miles away. This restriction of the seismic area is commonly attributed, and seemingly with justice, to a small depth of origin, less than half-a-mile in the Ischian earthquake, while the more extended shocks originate at a greater depth.

If we compare the extent of the Pamir earthquake of 1911 with the Ischian of 1883, both being of about the same degree of maximum violence, we are faced with very different conditions; although in both cases the maximum degree of violence was not very different, the area over which the one reached a destructive degree of violence was as great as the whole area over which the other could be felt at all. The great development of landslips in the Pamirs was due to the accidental coincidence of the epicentral area with a region where the carving of deep, narrow, and steep-sided river-valleys, through lofty mountains, had given rise to unstable conditions of the hillsides; but, apart from this, the earthquake differed in no material respect from the general run of great earthquakes, which give good records at long distances from the origin.

Of disturbances known to have originated on the surface, we have had, in the last few years, explosions of great magnitude and violence, which gave rise to surface-waves capable of record by seismographs at a distance; but, in all cases, these have been marked by the very restricted area over which the disturbance was sufficiently great to cause material damage: within a distance measurable in yards, damage, directly due to vibration of the ground, had ceased, and within a very few miles at most no vibration could be felt, even by those who were specially favourably situated. From these analogies we may conclude that, even if the fall of the Usoi landslip could have produced a shock sufficiently great to cause damage, this would have been limited to the immediate neighbourhood, and the earthquake would have ceased to become sensible before the limits of the region in which damage was actually done were reached.

The facts known of this earthquake show that it cannot have been of surface origin, but must, like other similar shocks, have had a deep-seated origin, not necessarily the 1200 or even the 200 kilometres, which have been claimed for some of the world-shaking earthquakes, but at any rate of the order of 50 kilometres or 30 miles. That it could not have been due to the fall of the landslip is evident; the landslip was determined by the earthquake and, so far as the time of occurrence is concerned, was a consequence, not a cause.

Yet it is possible that the impact of the great Usoi landslip, and of the many other great slips, which accompanied this earthquake and precipitated vast masses of rock into the valley-bottoms, may have had their effect in setting up surface-vibrations, and starting surface-waves, which were propagated afar, and left their impress on distant seismograms. In the course of the discussion, which led to this investigation, Mr. J. J. Shaw stated that the seismogram obtained at West Bromwich showed the third-phase (or long) waves, as unusually large in proportion to the preliminary tremors, which were of but small dimensions. This means that the surface-waves were of unusual size for a disturbance of the magnitude indicated by the mass-waves transmitted through the earth, and this greater development of surface-waves may not improbably have been due to the combination of wave-motion, started directly by the earthquake, with other surface-waves, originated by the landslips.

12. *The* Jurassic Rocks *of* New Zealand. By Charles Taylor Trechmann, D.Sc., F.G.S. *With an Appendix on* Ammonites *from* New Zealand, by Leonard Frank Spath, D.Sc., F.G.S. (Read June 22nd, 1921.)

[Plates XII–XVIII.]

Contents.

I. Introduction.

The Jurassic in New Zealand comprises a thick series of deposits, important both stratigraphically and structurally. In every locality where the sequence is well seen they follow closely the Triassic rocks with apparent perfect conformity. Compared with the underlying Trias, however, they exhibit contrast in a number of characters, among which are the following:—

(*a*) They are, generally speaking, less steeply inclined and enter less, so far as is at present known, into the structure of the Alpine mountain-ranges. No instance is known to me where rocks with recognizable Jurassic fossils occur in a slaty or semi-metamorphic condition as do the Triassic rocks in some places on the eastern fringes of the Southern Alps: for example, at Mount Potts and Mount St. Mary.

(*b*) The Jurassic, in contrast with the Trias, exhibits a much greater vertical range of marine fossiliferous deposits throughout its thickness, including horizons ranging from the lowest Lias to the Kimmeridgian and Tithonian. The Trias, on the contrary, is fossiliferous only in the higher beds, ranging from the Ladino-Carnic to the Rhætic.

(*c*) Jurassic rocks apparently occur over a rather greater length of the two islands than the Trias, although this is probably due merely to accidents of outcrop and exposure, since Trias much resembling that in New Zealand recurs in New Caledonia. The

Jurassic rocks at Waikawa occur at the extreme south-eastern corner of the South Island, and near the northern extremity of the North Island at Cape Maria van Diemen and Spirits Bay Mr. A. McKay has recorded rocks similar in lithological characters to the Jurassic and Trias of Nelson and Southland.[1]

(*d*) The general lithic characters, while on the whole similar, differ somewhat in detail from those of the Trias. There is the same absence of contemporaneous igneous rocks that one finds in the Trias,[2] but a greater development, especially perhaps in the Lias, of soft felspathic, glauconitic, and sometimes oolitic beds. The condition of the sediments often causes the fossils to be unsatisfactorily preserved. Beds of rounded granitic conglomerates frequently occur as they do in the Trias, and the nature of the included fragments seems to be very similar. Plant-bearing strata are frequent, especially in the higher beds, although I have seen drifted wood also in the lowest beds with marine fossils. At Waikawa the stumps of a fossil forest are preserved *in situ.*

In his commentary on the report of the Geological Survey during 1877–78 of the Hokonui Hills,[3] where the lithological characters of the Triassic and Jurassic rocks were worked out in greater detail perhaps than in any other region, Sir James Hector gives the following summary of the formations represented there:—

European equivalent.	*Series.*	*Thickness in feet.*
Upper Oolite.	Mataura.	3500
Middle Oolite.	Putataka.	850
Lower Oolite.	Flag Hill.	800
Lias.	Bastion.	2200
Upper Trias (Rhætic).	Otapiri.	1600
Middle Trias.	Wairoa.	3000
Lower Trias.	Oreti.	3400
Permian.	Kaihiku.	6150

He continues with a description of the beds, of which the following is a condensed account, and includes lists of names of the fossil mollusca and plants which were collected. The Mataura Series appears to consist largely of estuarine beds, marine fossils being absent or rare. It comprises dark marls and fine-grained sandstones, and contains the remains of a number of plants. The strata agree closely in mineral character with the plant-beds at Waikato Heads, 35 miles south of Auckland, in the North Island, and contain similar remains of fossil vegetation. Proceeding, he says that the Mataura Series which overlies the Putataka Series, closes the old Secondary sequence at Kawhia, in the Auckland district, and the same plants are found in the Clent Hills plant-beds. The Clent Hills are in Canterbury Province, some 70 miles

[1] Rep. Geol. Explor. 1892, p. 90.

[2] Prof. P. Marshall mentions what may be an exception to this rule, in his 'Geology of New Zealand' 1912, p. 187.

[3] Rep. Geol. Explor. 1878, Introduction, p. vii.

west of Christchurch. The Putataka Series, which also has its typical development at Waikato Heads and in the Hokonui district, is represented in the southern districts by coarse-grained sandstones which pass near the base of the formation into conglomerates, with bands of indurated shale enclosing plant-remains and irregular coal-seams. The Putataka Series is of marine origin. Hector refers to these rocks in the reports as the '*Astarte* Beds.' The Flag Hill Series, principally developed in the Hokonui Range in Southland, is in part marine, and is characterized by 18 forms of fossil shells. The fossil plants in the upper part of this group are the same as those found at Waikawa and Mataura Falls, and are especially interesting in that at least one species is identical with a plant found in the Rajmahal Beds of India (which are considered to be of Liassic age): namely, *Macrotæniopteris lata.*

The lower part of the Flag Hill Series is marine, and Hector gives a list of 18 names of English Oolite fossils. He says, moreover, that, besides seven forms of *Rhynchonella* and three of *Terebratula*, *Spiriferina rostrata* of the Lias is abundant, as also a form of *Epithyris.*

The Bastion Series consists in its upper part of conglomerates and sandy grits with plant-remains too indistinct for identification, and in the lower of marly sandstones in banded layers of different colours having at the base a concretionary structure which has led to its being termed cannon-ball sandstone. Similar sandstones occur also in the Otapiri formation. Fossils are plentiful, and divide the strata into distinct horizons. A list of fossils follows, and Hector goes on to say that the general facies of the fauna is (on the whole) Liassic, although many Lower Oolite forms occur; but that the brachiopoda, of which 21 forms have been provisionally distinguished, again present the same abnormal survival of older types, especially in the occurrence of an *Athyris*-like shell belonging to the new sub-genus *Clavigera*, which has a great development in the next formation below.

The Otapiri Series is placed in the Rhætic, but Hector says that the fossils include forms belonging to the Lias and Oolite. His list of fossils makes it clear, however, that he is here dealing with the beds of the Carnic and Noric Series of the Trias. I have already described both these beds and the Wairoa, Oreti, and Kaihiku Series in a previous paper.[1]

Hector gave lists of the fossils collected by the Survey in the Jurassic deposits, just as he gave lists for the Trias and supposed Permian. As these names are mostly those of well-known English fossils, they are of very little value, and therefore I have found it necessary to neglect almost entirely Hector's lists, and have relied primarily on the collecting done by Prof. P. Marshall and myself, as also on specimens lent to me by Prof. Marshall and Mr. J. A. Bartrum, and by the Director of the Geological Survey, about the locality of which there could be no question.

[1] 'The Trias of New Zealand' Q. J. G. S. vol. lxxiii (1917–18) p. 165.

In Prof. Marshall's company I collected from two or three localities in the Hokonui Hills and from most, if not all, of the known fossiliferous localities round the shores of Kawhia Harbour. Prof. Marshall also kindly lent and gave to me fossils that he had collected at Waikato Heads and in the coast-section south of Nugget Point in the far south-east of the South Island.

This does not exhaust the fossiliferous localities of the New Zealand Jurassic, but it represents the most important and typical sections and those where the fossils are perhaps best preserved. If a collecting expedition could be sent to all the localities, it would doubtless increase the known number of species; but I already possess a very representative series of the Jurassic fossils, from which it is possible to obtain a general idea of the particular marine Jurassic horizons present in the two islands.

Prof. Emile Haug has summarized the state of our knowledge, or lack of knowledge, of the Jurassic of New Zealand and adjacent areas in the Southern Hemisphere. He says, dealing with the Otapiri Beds which follow the Trias :—

'The marine fossils which have been mentioned under the names of *Belemnites otapiricus*, *Pleurotomaria ornata*, and *Tancredia truncata*, remind one of Liassic forms. Above come the Mataura Beds with *Macrotæniopteris lata* and *Tæniopteris daintreei*.' ('Les Périodes Géologiques' vol. ii, 1907, p. 992.)

Farther on, he says :—

'Recent works have made known several very fossiliferous horizons in the Inferior Oolite Series in several of the islands of the Malay Archipelago. The analogous formations that exist in New Zealand are unfortunately much less well known; . . . . . A *Stepheoceras* of the group of *humphriesianum*, a *Macrocephalites*, and some belemnites of the genus *Belemnopsis* are the only fossils on which one can rely to affirm the presence of the Inferior Oolite in New Zealand.'

Discussing the Upper Jurassic, Haug says :—

'The presence of the Tithonian in New Zealand is certain, since Hochstetter collected there an ammonite very closely related to *Berriasella* of Stramberg (*Ammonites neozelandicus*). But the labours of the local geologists have scarcely made clear the stratigraphical relations of the beds whence this form was derived. A form described by Zittel under the name of *Aucella plicata* is probably from more ancient beds. The horizon of several *Belemnopsis* described by Hector cannot be determined with certainty.' (*Op. cit.* p. 1109.)

Referring to New Caledonia, he proceeds :—

'The existence of the Upper Oolite in New Caledonia is founded on palæontological data of small precision, since the shales which form the base of the coal series, probably of Cretaceous age, only contain lamellibranchs and gasteropods that are specifically indeterminable. Piroutet cites, however, an *Aucella* related to *A. leguminosa* of the Spiti Beds.'

It will thus be seen that much remained, and indeed still remains, to be investigated regarding the age of the various Jurassic deposits in New Zealand, especially in the determination of the earliest and latest horizons, and the question as to whether a complete or more

or less incomplete sequence of these beds is represented. The intercalation of semi-marine or estuarine plant-bearing sediments among those which carry marine fossils is also an interesting feature, in view of the excellent work which was accomplished by the late Dr. E. A. Newell Arber on these floras.

I am indebted to Prof. P. Marshall for his company and assistance on several of my excursions in New Zealand, and for providing me with stratigraphical details and a map of the Kawhia and other areas, as also for the loan of specimens. My thanks are also due to Mr. P. G. Morgan, the Director of the Geological Survey of New Zealand, and to Dr. J. Allan Thomson, at one time Palæontologist to that Survey; also to Mr. J. A. Bartrum, of the College, Auckland. Several experts at home have kindly assisted me with the fossils: among these are Mr. S. S. Buckman, Dr. F. L. Kitchin, and Dr. L. F. Spath, who has undertaken the description of the ammonites.

II. The Jurassic Plant-bearing Beds of New Zealand.

An extremely important monograph has recently appeared, dealing with the plant-bearing beds of Triassic and Jurassic age.[1] As the evidence from the fossil plants does not seem in every case quite to agree with that of the marine faunas, it may be advisable to refer to some of these points.

The earliest flora, that of Mount Potts, is said to be Rhætic or Triasso-Rhætic in age. This result agrees, on the whole, with my determination of the Kaihiku marine fossils that occur at Mount Potts as Ladino-Carnic, and I have dealt with the matter in the paper on the Trias of New Zealand already cited.

The flora of the Clent Hills in Canterbury Province is also considered to be Rhætic, although, owing to the absence of certain forms, it may be slightly younger than the Mount Potts flora. The flora that occurs at Mokoia, near Gore in Southland, is put down as Lower Jurassic, though Mr. McKay referred to the beds as Triassic.

The flora at the Mataura Falls in Southland is said to be Lower rather than Middle Jurassic in age, and slightly younger than that at Mokoia. New Zealand geologists have referred the Mataura Beds to the Upper Oolite.

The plant-beds, including the fossil forest at Waikawa in the far south-east, are said to be probably of Middle Jurassic age, though Arber remarks that our knowledge of Upper Jurassic floras is very limited. The stratigraphical position of the beds should, however, refer them to a position high up in the Jurassic. Unfortunately, I know of no marine fossils associated with either the Mataura or the Waikawa plant-beds such as might confirm or refute these attributions.

[1] E. A. Newell Arber, 'The Earlier Mesozoic Floras of New Zealand' N.Z. Geol. Surv. Pal. Bull. No. 6, 1917.

Finally, the plant-beds at Waikato South Heads in Auckland are assigned to the Neocomian. S. H. Cox [1] refers to the plant-beds as part of the Mataura Series, while beneath them comes the Putataka Series, consisting of marlstones in which marine fossils were found. Among those identified were *Aucella plicata*, *Inoceramus haasti*, and *Belemnites aucklandicus*. The specimens of *Aucella* which Prof. Marshall and Mr. Bartrum collected at this locality are described on p. 267.

Quite recently, Mr. J. A. Bartrum [2] has published a note based on the examination by Prof. A. C. Seward of a collection of plants which the former collected at Waikato. The most interesting of these is said to be *Elatocladus plana* (Feistmantel). Mr. Bartrum writes to me that Prof. Seward is now inclined to doubt the Neocomian age of the Port Waikato plant-beds, and, though uncertain as yet, he prefers to think that they are probably older.

III. Description of Localities of Jurassic Rocks.

The South Island.

The Hokonui Hills.

In my paper dealing with the Trias of New Zealand I indicated roughly the structure of the Hokonui Hills; they consist of a trough of which only the northern and western sides are exposed. The northern and western fringes are occupied by the steeply-inclined beds of the Trias, while the inner and southern parts of the range are occupied by more or less horizontal Jurassic deposits which overlie them. The district was surveyed in great detail in 1877–78 by Mr. S. H. Cox & Mr. A. McKay,[3] and a map and several sections, together with a detailed lithological table of the strata, was published. Unfortunately, neither drawings nor descriptions of the fossils collected during the survey are supplied, and consequently a precise determination of the age of the beds is precluded.

Above the Upper Triassic Wairoa Series the following beds occur in ascending order:—Otapiri and Bastion Series, Flag Hill Series, Putataka Series, and Mataura Series.

In company with Prof. P. Marshall, I collected at the two following localities in the Jurassic rocks of the Hokonuis:—

(1) At the junction of Taylor's Creek with the Otapiri stream. The beds seem to be those marked No. 48 in the section along the line AB in the Survey report, described as lower cannon-ball sandstone, and as belonging to the top of the Otapiri, or

[1] 'Report on the Waikato District' N.Z. Geol. Surv.: Rep. Geol. Explor. 1877, p. 11.

[2] 'Note on the Port Waikato Mesozoic Flora' N.Z. Journ. Sci. & Technol. vol. iv (1921) p. 258.

[3] N.Z. Geol. Surv.: Rep. Geol. Explor. 1878, pp. 49–90.

the very base of the Bastion Series. They consist of dark decomposed felspathic sandstones, with big concretions. The beds are full of fossils, but only the larger forms are in a condition to make satisfactory determination possible. Species of the ammonite genus *Psiloceras* occur here, and several species of *Oxytoma* were found. Small indeterminable mollusca are very plentiful, including species of *Pecten*, a small concentrically-ribbed *Astarte*, a small wedge-shaped lamellibranch (possibly a form of *Tancredia*), and Naticoid gasteropoda. Fossil drift-wood also occurs in the rock. The ammonites refer the beds to the Hettangian.

(2) The second locality was some distance up the slope of Flag Hill in beds, apparently those called the '*Plagiostoma*' Beds, numbered 53 in the same section, and indicated as rather above the middle of the Bastion Series. They consist of fine-grained sandstones, several blocks of which are scattered about the grassy slopes, and contain abundant specimens of a bivalve shell that I have named '*Pseudomonotis*' *marshalli*. This may be the fossil referred to as '*Plagiostoma*' by the geological surveyors. The fossils are all casts, and the shells are replaced by a rusty material. Several of the smaller forms are specifically indeterminable, among them being a small patelliform gasteropod. Others include a small, adherent, *Gryphæa*-like, ostreiform bivalve, and another resembling a *Pleuromya*. The Rhynchonellids have a 'Callovian' aspect.

The Survey report mentions *Astarte* Beds as occurring at the top of Flag Hill. These may be the equivalents of the beds with *Astarte* of the group of *A. spitiensis* at Totara Point, Kawhia; but, as we did not visit the top of the hill, I cannot be certain about this.

In still higher beds in the Hokonui district *Inoceramus* is recorded, although whether this refers to *I. haasti* or not, I cannot say.

The South-Eastern Coast of the South Island.

Following the direction of their strike in the Hokonui Hills, both the Trias and the Jurassic appear on the south-eastern coast of the South Island, where they are continued out to sea. The steeply-dipping Triassic sequence is found from Nugget Point to the southern end of Shaw Bay or Roaring Bay. South and south-west of this the coast is occupied by Jurassic rocks as far as Waikawa, where the fossil forest occurs. The coast south-west of Roaring Bay and about the Catlins River is difficult of access; but Prof. Marshall has recently visited it, and informs me that he found *Inoceramus* in a bed which strikes east-south-eastwards to the boat-landing at Catlins, and on the strike of this bed at the coast he found some belemnites. The boat-landing is precisely a mile from the Rhætic beds of Roaring Bay, and, as the direction is at right angles to the strike and the dip averages 70° to 75° south-westwards, the thickness of the rock separating the localities is

almost exactly 5000 feet. About half-way between these two points, a short distance north of Sandy Bay, there is a stratum particularly rich in a lamellibranch, of which Prof. Marshall has sent me specimens. The horizon is 2500 feet above the Rhætic bed. The shells here mentioned are those described on p. 269 as *Aucella (?) marshalli*, sp. nov. Prof. Marshall writes that there are probably many fossils to be obtained between Roaring Bay and Sandy Bay; but the coast is rough, and collecting requires much time.

Among the fossils that he sent to me for inspection are *Inoceramus* cf. *galoi* Bœhm from Kerrs, south-west of Nugget Point, and a poorly preserved *Astarte* apparently belonging to the group of *A. spitiensis* Stolickza. The poor condition of the other fossils, however, prevents accurate specific determination.

The beds are apparently the same as those at Totara Point, Kawhia, where the *Astarte* of the *spitiensis* group occurs.

The North Island.

The Waikato District.

The Waikato River reaches the western coast of the North Island about 45 miles north of Kawhia. The Jurassic rocks are found on the south side of the river-mouth, the north side being covered with blown sands. The district was surveyed by Mr. S. H. Cox[1] in 1876–77; it has been visited by Prof. Marshall, and more recently by Mr. J. A. Bartrum. As at Kawhia, the Jurassic deposits are unconformably overlain by Tertiary limestones. At the South Heads the beds form an anticline; the marlstones, (Putataka Series) according to Mr. Cox, are highly fossiliferous, and constitute the central core of the anticline, the axis of which runs about due north-west. These beds are reported to be at least 500 feet thick, and are overlain by alternations of sandstones and sandy marls, with occasional slaty beds in all of which are plant-remains in a more or less perfect state of preservation, but in many cases very indistinct. These are the famous plant-beds of the Mataura Series.

Mr. Bartrum has sent me a series of marine fossils which he collected there. The *Aucellæ* all belong to the forms which Prof. Marshall also collected at the South Heads, and resemble those figured in Pl. XIV, figs. 5–7, namely *A. spitiensis* and *A. blanfordiana*.

None of the species now called *A. plicata*, by Bœhm, of the *Inoceramus-haasti* Beds of Kohai Point, Kawhia, appear in the collection. The remaining fossils include *Trigonia* sp. (very obscure); also *Parallelodon egertonianus* Stoliczka, a small specimen; a small radially-ribbed and thick-shelled bivalve,

[1] 'Report on the Waikato District' N.Z. Geol. Surv.: Rep. Geol. Explor. 1877, p. 19.

apparently a *Limea*; Serpulid tubes, one recalling *S. convoluta* Goldfuss attached by the apex, and curled both dextrally and sinistrally; another resembling the genus *Pyrgopolon*.

Kawhia Harbour. [By Prof. Patrick Marshall, M.A., D.Sc., F.G.S.]

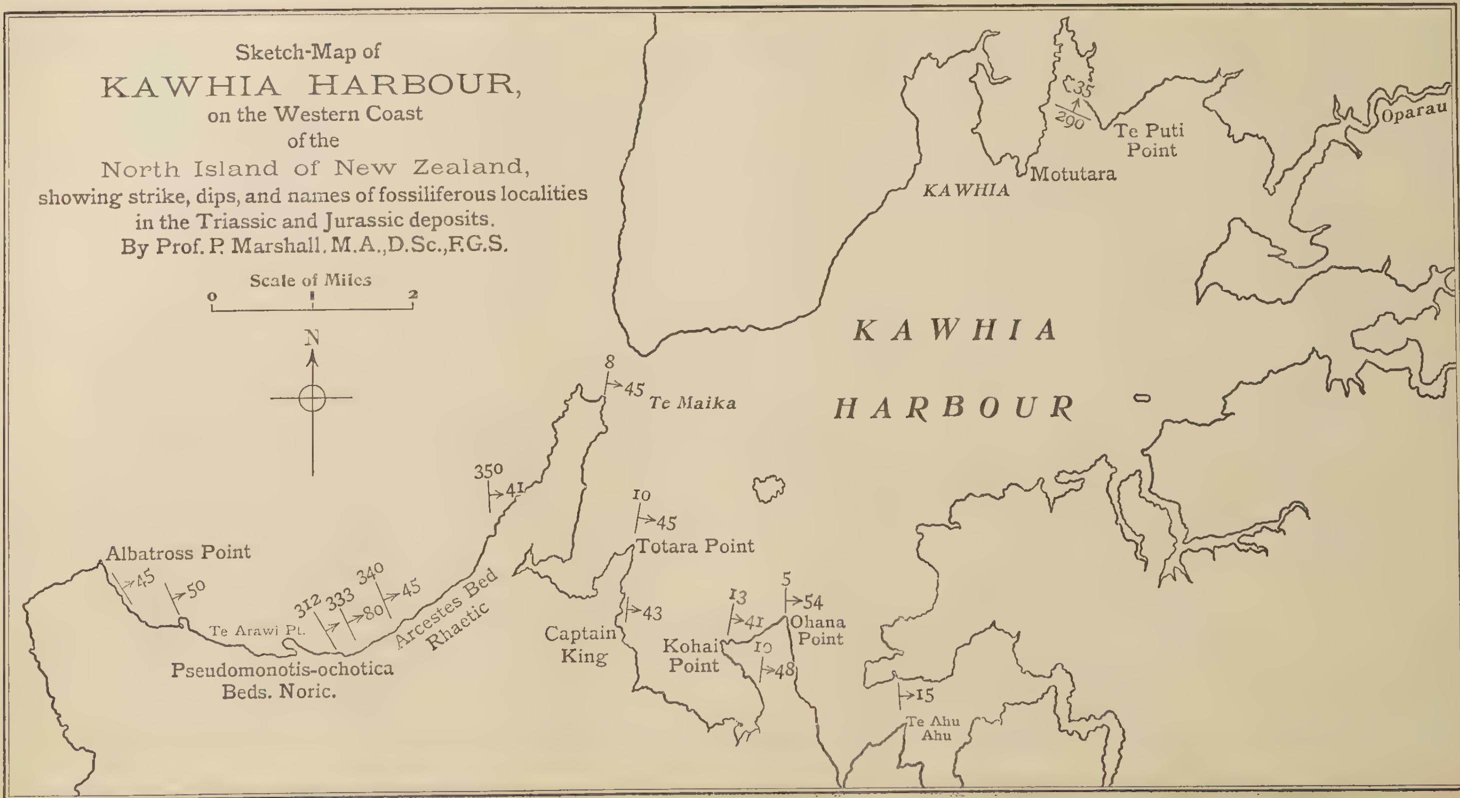
Early in 1915 I paid a visit to Kawhia in company with Prof. Marshall. Most of my time was spent in collecting the fossils of the various outcrops, but Prof. Marshall (who had visited the locality on previous occasions) has sent me the accompanying map and description of the strata represented in the district.

Near Te Arawi, where the *Pseudomonotis* Bed (Noric) is situated, there is a large intrusion of porphyrite. This, however, does not much affect the sedimentary strata. The *Pseudomonotis* Bed is a fine-grained grey sandstone. This type of rock is continued along the cliff-face almost to Te Maika, though it varies somewhat in coarseness. Occasionally, there are thin bands of a fine conglomerate. The stratification is quite regular, the strike gradually swinging to the north. It is 312° at the *Pseudomonotis* Beds, but has changed to 340° where the ammonite (*Arcestes* cf. *rhæticus* W. B. Clark) was found. Thence it gradually becomes more northerly, and at Te Maika, $3\frac{1}{2}$ miles distant, it is 8°. Locally small changes in the strike can be observed, though in all cases the normal direction is soon regained. There are a few faults, but these appear to be of no importance and of no great magnitude. The small bands of conglomerate in this part of the section are not of any consequence.

Farther west towards Albatross Point, on the farther side of the porphyrite intrusion, massive beds of conglomerate occur, and the strike of the rocks becomes much more westerly. No fossils were found in that part of the cliff-face. At Te Maika thick beds of conglomerate occur. The pebbles are seldom more than 6 inches in diameter, and are well rolled: they consist mainly of granophyre and other kinds of quartz-porphyry, and even granite-porphyry. No rocks of this type occur at the present day *in situ* in the North Island, and they are unusual in the South Island.

At Totara Point the strike is almost the same as at Te Maika. The rocks at this point are only about 530 feet higher in the section than those at Te Maika Point. The beds at Totara Point are also conglomerates of the same nature as those at Te Maika. Ammonite-beds and a bed of other mollusca occur closely below the conglomerate. These beds are gritty, and in places almost glauconitic. On the other side of the small bay at Kohai Point the rock becomes finer, and is in effect a mudstone. The strike, however, is practically the same as at Te Maika, and the dip remains about 45°.

At Ohana Point another bed of conglomerate occurs, having the same character and composition as those described before.


Sketch-Map of
KAWHIA HARBOUR,
on the Western Coast
of the
North Island of New Zealand,
showing strike, dips, and names of fossiliferous localities
in the Triassic and Jurassic deposits.
By Prof. P. Marshall. M.A., D.Sc., F.G.S.
Scale of Miles
0
2
N
KAWHIA HARBOUR
KAWHIA
Motutara
Te Puti Point
Oparau
Te Maika
Totara Point
Captain King
Kohai Point
Ohana Point
Te Ahu Ahu
Albatross Point
Te Arawi Pt.
Pseudomonotis-ochotica Beds. Noric.
Arcestes Bed Rhaetic

At the next point, Te Ahu Ahu (the old Wesleyan Mission Station), the rock is a fine-grained slightly concretionary mudstone. The stratification is here somewhat disturbed; but, except for purely local variations, it appears to be much the same as at the other points on the south side of the Harbour.

At Motutara, on the north side of the Harbour, the rocks are extremely concretionary, and here have a very different strike. They exhibit the characteristics of a fine mudstone.

Assuming that there is no faulting of importance between the *Pseudomonotis* Bed and Totara Point (and actually there seems to be none), then the strata between these localities must have a thickness of about 11,000 feet, and another like thickness must separate the beds at Totara Point from those at Te Ahu Ahu.

Since there is an almost continuous section between these points, and since the stratification and strike and dip are throughout extremely regular, it is reasonable to assume that the thickness of the rocks from the *Pseudomonotis* Bed to Te Ahu Ahu is some 20,000 feet.

IV. Conclusions regarding the Age of the New Zealand Jurassic Deposits.

It has been remarked that the Jurassic deposits in New Zealand follow the Trias with apparent conformity. It is very probable that, if the passage-beds in those districts where they are well seen (such as Kawhia and the Hokonui Hills) were well searched, some interesting fossils, especially among the brachiopods, would be found. It is also possible that representatives of the Rhætic beds containing *Avicula contorta*, corresponding with the Napeng Series of Burma, might be traced. I have illustrated a bivalve which recalls that form; but it is unfortunately too poor for accurate determination.

The lowest Jurassic rocks in which Prof. Marshall and I collected are those at the junction of Taylor's Creek with the Otapiri Stream in the Hokonui Hills. These beds contain two or more species of the genus *Psiloceras*, of Hettangian age. The occurrence of higher marine fossiliferous Liassic deposits is indicated by certain ammonites in the British Museum, described in the Appendix, § VIII.

The fossiliferous deposits at Totara Point, Kawhia, yield some brachiopods that recall those of the Putchum Beds of India, which are referred to the Bathonian. These are *Terebratula acutiplicata* Kitchin, and *Rhynchonella pulcherrima* Kitchin. A Rhynchonellid bearing long spines in the Totara-Point Beds is thought to be a spinous development of the latter form. *Pecten (Camptonectes) lens* is a well-known Bajocian and Bathonian fossil.

On the other hand, several of the Totara-Point fossils closely resemble those from Wai Galo in the Sula Islands, which Bœhm refers to the Oxfordian, after a lengthy discussion of the relations of the fossils to those of the Charee Group of Kutch. These

include *Phylloceras* cf. *mediterraneum* (Neumayr) and *Inoceramus* cf. *galoi* Bœhm.

The brachiopods that we collected on the slopes of Flag Hill in the Hokonui Hills, according to Mr. S. S. Buckman, present a Callovian aspect.

The beds at Kohai Point, Kawhia, containing *Inoceramus haasti* and *Aucella plicata* have yielded no ammonites, so far as I am aware; but they cannot be far above those of Totara Point, and *I. haasti* is evidently related to *I. galoi*. I collected a *Phylloceras* on the shore not far below the *I.-haasti* Beds.

The beds at the Mission Station of Te Ahu Ahu yield belemnites very similar to those from the Oxfordian of the Sula Islands.

Considering the absence in all the last-mentioned localities of ammonites other than the relatively long-lived Phylloceratidæ, it seems possible to make only an approximate determination of their age, and to conclude that they fall into the Bathonian-Callovian-Oxfordian series of deposits.

The highest Jurassic beds in which we collected, at Te Puti on the northern shore of Kawhia Harbour, appear to be of Tithonian age. Probably more than one horizon is represented in the cliffs, since all the ammonites were found washed out and lying on the shore. These include *Uhligites hectori* Spath and *Aulacosphinctoides brownei* (Marshall), and their age is discussed by Dr. Spath (p. 298).

The evidence for the presence of still higher beds in the New Zealand Jurassic sequence is chiefly founded on the occurrence of *Berriasella novoseelandica* (Hauer), but the locality of this specimen seems somewhat doubtful.

The marine fossiliferous Jurassic series of New Zealand, therefore, commences with the lowest Lias and closes with beds representing the Tithonian. The oldest marine Cretaceous beds of the covering series of strata, according to Mr. Henry Woods,[1] are of Gault age, the equivalent of the Lower Utatur Beds of Southern India. These occur in the Clarence Valley in the north-eastern part of the South Island, and were found by Dr. J. Allan Thomson. Further transgressions are represented by the *Conchothyra-parasitica* Beds of Upper Senonian age.[2]

The intervening epoch, Tithonian-Albian, may appear inadequate to account for the great Mesozoic orogenic uplift and subsequent denudation and planation that affected the New Zealand area; but the evidence points to the fact that it must have been accomplished during this interval. Prof. Marshall writes [3] :—

'The close of the Trias-Jura is on all sides regarded as the critical period

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[1] 'The Cretaceous Faunas of the North-Eastern Part of the South Island' N.Z. Geol. Surv. Pal. Bull. No. 4 (1917) p. 2.

[2] C. T. Trechmann, Geol. Mag. 1917, p. 296.

[3] 'Handbuch der Regionalen Geologie' Heft 5, vol. vii, pt. 1 (1912) p. 36.

in the geological history of New Zealand. A great earth-pressure acted at its close, and all the areas of Mesozoic sediments were folded and apparently greatly elevated. The strike of the folds is remarkably uniform throughout the greater part of the country. From Mount Cook through the northern part of the South Island, and through the North Island from Cape Terawhiti to Poverty Bay the direction is constantly north-north-east.'

V. Relationship to the Jurassic Deposits of Adjacent Areas.

The Jurassic, as well as the Trias of New Zealand, offers a great contrast with that of Eastern Australia and Tasmania, a contrast somewhat analogous to that between the Trias of the Himalayas and that of Peninsular India.

Marine fossils of Jurassic age, however, occur in Western Australia, where the beds form a remanié series, reposing upon the underlying schists and gneisses. The horizons represented appear to be the Bajocian and the Callovian. The fossils include *Belemnopsis* and the familiar bivalves *Oxytoma münsteri* and *Pseudomonotis echinata*.

The Jurassic of New Zealand agrees in general features with that of most other regions in the great *circum*-Pacific belt. The Jurassic of New Caledonia, so far as I can ascertain, is very little known, but the resemblance of its Trias to that of New Zealand is probably shared by the Jurassic also. Marine Lias occurs there, but the horizon seems uncertain. Marine Lias is also found in Borneo (Toarcian); Annam; Japan (Toarcian); Alaska (Toarcian or Aalenian); California; Nevada and Oregon (Sinemurian, etc.); Peru and Chile (Sinemurian-Aalenian).

VI. Palæontology of the New Zealand Jurassic.

(*a*) Belemnitidæ.

Canaliculate belemnites seem to play nearly as great a part in the Jurassic of New Zealand as they do in that of the Moluccan Islands. G. Bœhm says [1]:—

'I have collected many hundreds of them in the outcropping beds of the Lower Malm, in the Island of Taliabu, and also farther east, and in the Island of Misol also in outcropping beds, and have left behind many thousands uncollected.'

He goes on to say that in the bed of the Lagoi Stream, in the forests of Taliabu, masses of *Belemnites alfuricus* Bœhm occurred.

In New Zealand I collected examples from three distinct localities and horizons on the northern and southern shores of Kawhia Harbour. Some of these are comparable with figures of belemnites recently issued,[2] named *B. canaliculatus aucklandicus* Hauer

[1] 'Die Südküsten der Sula-Inseln Taliabu & Mangoli' Palæontographica, Suppl. iv, pt. 2 (1907) p. 53.

[2] N.Z. Geol. Surv. Pal. Bull. No. 1 (1913) pl. v, figs. 2 & 4. [Plates by J. Hector.]

and *B. hochstetteri* Hector, but the exact locality of neither of these is recorded. Rather than waste time in discussing the nomenclature of these specimens, I propose to describe the best-preserved examples that I collected and indicate the relations which they seem to bear to those of other localities, especially the forms recorded by Bœhm from the Sula Islands. Bœhm quotes Gürich's remark that

'The belemnites from Rotti resemble outwardly the Middle Jurassic *Bel. canaliculatus*; a closer examination, however, reveals that they belong to the group of *Bel. absolutus*. The most nearly related, perhaps even identical, form is *Bel. gerardi* Oppel from the Spiti Shales of the Himalaya.' (*Op. cit.* pp. 54–55.)

Farther on, he says that in the cross-section of *B. gerardi* the ventral sulcus of the rostrum does not cut into the concentric calcareous rings, but rather that each single ring agreeing with the sulcus is embayed to an equal extent. This feature is observable in the cross-section, wherever I have seen it, in the examples from the Jurassic of New Zealand.

Careful zonal collecting in New Zealand is very advisable, since, from the few specimens that I obtained at Kawhia, it appears that those from the Mission Station at Te Ahu Ahu are distinct from those in the higher beds at Te Puti, while both these are distinct from the form that occurs at Totara Point in beds which may be approximately of Bathonian age.

BELEMNITES (BELEMNOPSIS) sp. (Pl. XVI, fig. 14.)

Description.—The following description is from a specimen nearly all the guard of which is present, but none of the alveolar region. The specimen is slightly distorted. Near the posterior end the cross-section is almost circular, but about the middle it becomes rather wider than high. The ventral sulcus extends for the whole length of the guard to the point, and is rather deep and narrow with a rounded floor and rounded slopes. The guard increases gradually in section from the anterior part until about two-thirds of the distance to the apex where the section is greatest, whence it tapers gradually to the apex.

Dimensions.—Length=68 mm.; at the thickest part the section is 6·5 mm. wide, and 5·5 mm. in a ventro-dorsal direction.

Locality.—Totara Point, Kawhia.

Remarks.—Mr. Buckman reports on this specimen—

'*Belemnopsis* sp. cf. *B. fleuriausus* A. d'Orbigny of the Great Oolite and *B. parallelus* Phillips of the Fuller's Earth (=Great Oolite *pars*). The apex is less elongate than in the first species. Bathonian.'

Numerous belemnites occur in the glauconitic nodular greensands at Totara Point. Most of them are curiously bent and distorted, this being apparently the result of movement in the rock at some period subsequent to deposition. All the specimens and fragments collected seem referable to one species, although further search may yield others.

Belemnites (Belemnopsis) sp. (Pl. XVI, figs. 15 & 16.)

Description.—The guard increases very gradually from the alveolar region to a point some distance behind it, maintains the greatest section for a short distance, and then tapers gradually to the apex. The ventral furrow is more or less broad with rounded floor and sides, and extends from the alveolar region nearly or quite to the apex. In this respect it differs from the belemnites in the higher beds at Te Puti, in which the furrow is less pronounced and dies away before reaching the apex.

Dimensions.—Length of guard = about 90 mm.

Locality.—Te Ahu Ahu, Kawhia. Near the old Wesleyan Mission Station, where rolled fragments are common on the shore.

Remarks.—Two broken guards in my collection may belong to different species. The cross-section is more nearly circular, and the ventral furrow is broader and shallower in one than in the other. They agree well with *B. taliabuticus* G. Bœhm [1] (pl. xi, figs. 5 *a*–5 *c*, 6 *a*–6 *c*, 7–8, especially figs. 5 & 6 and cross-section, fig. 8). The ventral furrow resembles that in *B. galoi* Bœhm (pl. x, fig. 5 *b*); but the cross-section in that form is considerably wider than it is dorso-ventrally, and the guard is widest towards the apex. They also resemble *B. alfuricus* Bœhm, a form which is very near to *B. gerardi* Oppel of the Spiti Shales. *B. galoi*, *B. taliabuticus*, and *B. alfuricus* occur in the 'Oxfordian' beds of Wai Galo, in the Island of Taliabu.

Belemnites (Belemnopsis) sp. (Pl. XVI, fig. 12.)

Description.—The ventral furrow is faint, and extends from the alveole backwards to within three-quarters of the length to the apex. At first, it is narrow and rather deep, but gradually widens out, becomes shallower, and disappears. Where it disappears, and towards the apex, the cross-section of the guard is nearly circular. The narrowest part of the guard is immediately behind the alveolar region, where it measures 10 mm. across and 11 or 11·5 mm. ventro-dorsally. At the thickest part, which occurs where the ventral furrow begins to die away, it measures 10·5 mm. across and 12 mm. ventro-dorsally.

Very faint, broad ventro-lateral furrows extend backwards for some distance behind the alveolar region. If one uses a lens, the surface of the guard is seen to bear very faint longitudinal striæ.

Dimensions.—The length of the guard and part of the alveolar chamber of one specimen is 82 mm. Another less perfect specimen has been about 110 mm. long.

Locality.—Te Puti Point, Kawhia, Upper Jurassic; found *in situ* in the cliff.

Remarks.—This belemnite does not seem to agree exactly with any of the forms figured by Bœhm from the Sula Islands, but comes nearest apparently to *B. lagoicus* Bœhm, except that in the

[1] 'Die Südküsten der Sula-Inseln Taliabu & Mangoli' Palæontographica, Suppl. iv, pt. 2 (1907) p. 73.

New Zealand examples the furrow extends farther towards the apex, while the apex is blunter and the guard is rather thicker.

BELEMNITES (BELEMNOPSIS) sp. (Pl. XVI, fig. 13.)

Description.—The ventral furrow is faint and shallow, and extends from the alveolar region backwards to three-quarters of the distance to the apex, where it gradually widens, becomes shallower, and disappears. The cross-section is nearly circular throughout, gradually increases posteriorly, and is thickest (6 mm.) about where the furrow dies away; it narrows thence to the apex, which is rather acutely pointed.

Dimensions.—A specimen comprising the guard and a small part of the alveolar chamber has a length of 70 mm.

Locality.—Te Puti Point, Kawhia, *in situ* in the cliff.

Remarks.—This belemnite seems to be a distinct species from the last-described one. I possess a perfect guard from which the description was drawn up, and others more or less fragmentary. It is comparable in some ways with a specimen described as *B.* cf. *lagoicus* Bœhm, but is smaller and narrower, and the furrow in the New Zealand example extends farther backwards.

B. lagoicus Bœhm occurs at the fossil locality on the Upper Lagoi River, on the Island of Taliabu, in beds which are thought to approach the junction of the Jurassic and Cretaceous. The belemnites at Te Puti, therefore, seem to agree with the ammonites, found lying on the shore there, in pointing to a high Jurassic horizon, probably Kimmeridgian.

(*b*) Gasteropoda.

PLEUROTOMARIA sp. (Pl. XII, figs. 11 *a* & 11 *b*.)

Description.—Shell thick, consisting of five or six whorls, increasing rather rapidly. Spire depressed, almost flattened, sutures excavated, and whorls concave above, sloping to the suture, decorated with a line of coarse blunt nodes, just below which, and a short distance above the suture, traces of the slit-band are visible. The outer keel is decorated with a line of smaller nodes. The shell is widely and deeply umbilicate below, the sutures being deeply excavated. The whorls are swollen below, and are decorated with a line of coarse and irregular nodes which point rather anteriorly. Growth-lines are well-marked and irregular.

Dimensions.—Diameter = about 40 mm.; height = about 17 mm.

Locality.—The lowest part of the Lower Ammonite-Bed at Taylor's Creek (Hokonui Hills), below the woolshed, collected by Mr. A. McKay in 1878, locality No. 358. The horizon is given as Lias. Remains of other fossils on the rock show that it is Jurassic, and not Trias. Hettangian (?).

Remarks.—A fragmentary cast in the N.Z. Geological Survey collection yielded gutta-percha squeezes from which the diagnosis

and illustrations were made. It resembles the group of *P. actinomphala* Deslongchamps of the Inferior Oolite and *P. mirabilis* Deslongchamps of the Middle Lias. The depression of the spire and the size of the umbilicus and strength of the nodes, both above and below, are remarkable features.

Amberleya zealandica, sp. nov. (Pl. XIII, fig. 12.)

Description.—Shell thin, consisting of seven inflated whorls, which increase rather rapidly in size. On the penultimate whorl are three ridges, the first of which is situated rather less than half of the distance of the whorl below the suture. The third or lowest ridge occurs a short distance above the suture, and is rather less prominent than the other two. The last whorl bears seven ridges which gradually decrease in size, the first two being about equally prominent, the second being perhaps very slightly the larger. The first ridge occurs rather more than a third of the distance between the suture and the base of the whorl. The space between it and the suture is concave, and on it the faintest trace of another ridge can be seen a short distance above the main ridge. The larger growth-lines are regular and sharp, and somewhat foliaceous, producing a series of sharp tuberculations on the ridges. They sweep strongly backwards and then forwards, and continue below the first ridge with a slight forward inclination. The aperture is not visible, and the shell on the earlier whorls is missing.

Dimensions.—Height=21 mm.; height of last whorl=10 mm.; diameter of the same=14 mm.

Locality.—Totara Point, Kawhia.

Remarks.—This shell apparently belongs to the group of *A. capitanea* Münster and *A. ornata* Sowerby. In the rather swollen outline of the whorls it recalls the Upper Liassic form *A. capitanea* rather than the more sharply ridged *A. ornata*, but the first ridge is situated farther below the suture than in *A. capitanea*, and the surface is more concave. It would be unwise, I think, to refer it definitely to either of these Europæan forms, especially since W. H. Hudleston regards *A. ornata* as a modified descendant of *A. capitanea* on a higher horizon.

Cerithinella sp. (Pl. XIII, fig. 13.)

Description.—Shell subcylindrical, consisting of ten or eleven whorls which increase gradually in size. The whorls are nearly flat, and the sutures impressed. Below the sutures is a row of nodes, and below these about six concentric raised spiral lines, which are more or less broken up into small nodes by the growth-lines. The base of the last whorl is decorated with similar concentric raised lines. Neither the apex nor the aperture is well seen.

Dimensions.—Height=24 mm.; height of body-whorl=6 mm.; diameter of the same=6 mm.

Locality.—Totara Point, Kawhia.

Remarks.—The specimen described belongs to the N.Z. Geological Survey. It seems to be rather closely related to *C. bajociensis* [1] or some variety of that shell which occurs at Bradford Abbas. Shells apparently belonging to this form are plentiful in the sandstones with *Inoceramus* cf. *galoi* at Totara Point, but are generally so poorly preserved that the decoration is invisible.

(*c*) Lamellibranchiata.

Leda sp. (Pl. XV, fig. 5.)

Description.—The beak is situated rather forward of the middle of the shell, which is strongly rostrate posteriorly, the rostrate portion having a slight upward curve. This rostrate portion is decorated with growth-lines only. Nearly all the rest of the surface is ornamented with faint rather wrinkled ribs, mostly directed downwards and forwards, but which both below and in front of the beak assume an angular V-shaped character. The V-shaped decoration does not persist to the anterior margin, where the ornamentation becomes very faint.

Dimensions.—Length = 22 mm.: height = 8 mm.

Locality.—Slope of Flag Hill, Hokonui Hills. Callovian (?).

Remarks.—The illustration is sketched from a gutta-percha squeeze of the impression of the right valve. This shell belongs to the group of *L. rostralis* Lamarck and *L. graphica* Tate, which occur in the English Lias, but the V-shaped decoration extends over more of the surface in the New Zealand specimen than it does in the English forms, where it seems to be more restricted to the posterior surface behind the beaks.

Parallelodon egertonianus Stoliczka. (Pl. XIV, fig. 8.)

1865. *Macrodon egertonianus* Mem. Geol. Surv. Ind. vol. v, p. 89 & pl. viii, fig. 7.

Description.—The beaks are broad, swollen, flattened, close together, and are well raised above and bent over the hinge-area, which is rather wide, concave, and grooved. The anterior margin of the shell is produced along the hinge-line to a rather sharp point, the lower anterior margin being gently rounded. The primary costæ are fine and regular, and radiate from the beak; finer secondary ribs occur between the primary ribs about half-way from the beak to the lower margin. The ribs become much more widely and irregularly spaced on the anterior portion of the shell.

Dimensions.—Height = 21 mm.; length originally = about 45 mm.

Locality.—Waikato.

Remarks.—The figured specimen consists of part of the left valve well preserved and of the corresponding right valve with

[1] W. H. Hudleston, 'Monogr. Brit. Jur. Gasteropoda' 1890 (Pal. Soc.) p. 186 & pl. xii, fig. 3.

only part of the shell remaining, and the posterior part of both valves missing. The locality is rather uncertain, but apparently the shell came from Waikato. Mr. J. A. Bartrum has recently sent me, among other fossils that he collected at Waikato, a small and well-preserved specimen of this shell measuring 16 mm. in length and 9 mm. in height, which confirms its specific attribution, and shows that the ribs become nearly obsolete at the posterior portion of the shell. It also shows the curious feature mentioned by Dr. K. Holdhaus and Mr. R. B. Newton, namely, that the right valves of all the specimens have a series of intermittent ribs between the prominent radiating costæ, which are entirely absent on the left valve, where the costæ are fewer and wider apart.

The species is a well-known one from the Spiti Shales of the Himalayas.[1]

Mr. R. B. Newton [2] has recorded the interesting fact of the occurrence of this shell in a river-bed at Bihin, in Somaliland. He also records it from near Dihala, north of Aden, in beds supposed to be of Corallian age.[3]

Among the Australian Cretaceo-Jurassic lamellibranchs from the Desert Sandstone of Maryborough, in Queensland, *Cucullæa robusta* R. Etheridge fil. is very suggestive of this form.[4]

Aucella.

The *Aucellæ* that I possess from New Zealand offer some puzzling features: they are from three distinct localities, and probably also from as many distinct horizons:—

(1) Kohai Point, Kawhia Harbour, where they occur associated with *Inoceramus haasti*.
(2) Specimens from the South Head at Waikato, collected by Prof. P. Marshall and Mr. J. A. Bartrum.
(3) Specimens of a new form, doubtfully referable to the genus *Aucella*, collected by Prof. Marshall on the south-eastern coast of the South Island.

The original specimens collected by the *Novara* Expedition and described by Zittel as *A. plicata* [5] came from the South Head at Waikato. The illustrations comprise three views of one specimen, are not very clear, and seem to represent a shell with part of the margin broken away. Bœhm, however, examined seven specimens

[1] K. Holdhaus, 'Fauna of the Spiti Shales (Lamellibranchiata & Gasteropoda)' Pal. Ind. ser. 15, vol. iv (1913) p. 434 & pl. xcv, figs. 1–10.

[2] 'On the Occurrence of an Indian Jurassic Shell, *P. egertonianus*, in Somaliland' Geol. Mag. 1896, p. 294.

[3] Ann. & Mag. Nat. Hist. ser. 8, vol. ii (1908) pl. i, figs. 1–4.

[4] J. L. Jack & R. Etheridge, 'Geology & Palæontology of Queensland' 1892, p. 565 & pl. xxvi, figs. 1 & 4.

[5] 'Paläontologie von Neu-Seeland' 1864, p. 32 & pl. viii, figs. 4 *a*–4 *c*; the plate is also reproduced by Prof. J. Park in his 'Geology of New Zealand' 1910, p. 78.

collected by the *Novara* Expedition which are preserved in the Vienna Museum, and gives a description and enumeration of them.[1] He also had five specimens from Kohai Point and four specimens from a place near Totara Point called Captain King, which were collected for him by Mr. H. Suter in 1905.

Zittel's description of *A. plicata* lays emphasis on the concentric, rather widely-spaced folds which are said to be stronger than in any known form. The radial sculpture is not mentioned, but Bœhm, as a result of his examination of the *Novara* material, says that it is apparent on two of the original specimens.

Bœhm refers his specimens from Kawhia to Zittel's species *A. plicata*. Those that I collected at Kohai Point, Kawhia, are quite distinct from the forms that were collected at Waikato, all of which resemble very closely the *Aucellæ* of the group of *A. spitiensis* and have no radial ornamentation.

I did not visit Waikato, and so I cannot say from personal observation whether the small arched form which occurs at Kawhia with *Inoceramus haasti* occurs there also, but Prof. Marshall informs me in a letter that he did not find it there. The N.Z. Geological Survey report on the district states, however, that *I. haasti* is found at Waikato, and so it is possible that both forms of *Aucellæ* occur there, that related to *A. spitiensis* representing possibly a higher horizon than the other species.

It seems not improbable that some of the *Novara* specimens from Waikato may have become mixed up with those from Kawhia. Hochstetter collected *Inoceramus haasti* at Kawhia, and could scarcely have failed to collect the *Aucellæ* that occur in the same bed with it.

However, in order to avoid any further confusion on this point, I shall describe as best I can the material in my hands, indicating the localities whence it came, leaving the further problems to be solved by future search in New Zealand.

It seems uncertain whether the *Aucellæ* from the *Inoceramus-haasti* Beds really belong to the form from Waikato, which Zittel calls *A. plicata*; but, as Bœhm unites them under that name, I follow his example with regard to the specimens that I collected.

Dr. K. Holdhaus[2] remarks that he has seen the types of *Aucella plicata*, and is assured that they represent a true *Aucella* very closely allied to *A. pallasi* Keyserling and *A. blanfordiana* Stoliczka.

Prof. E. Haug says that Piroutet cites the occurrence in New Caledonia of an *Aucella* related to *A. leguminosa* of the Spiti Beds.

Unfortunately, the *Aucellæ* yield little information regarding the horizon of the beds in which they occur. Those known from the Southern Hemisphere bear so little resemblance to those from the Northern, excluding India, that correlation is almost

[1] Neues Jahrb. vol. i (1911) p. 11.
[2] 'Fauna of the Spiti Shales, &c.' *op. cit.* p. 405.

impossible. The place of origin of the genus[1] is a point on which much discussion has taken place with little result, as G. Bœhm thinks.

AUCELLA PLICATA Zittel. (Pl. XVII, figs. 4–8.)

Description.—Left valve more or less strongly arched, sometimes narrow and laterally compressed, the outline being in consequence very variable. Beak prominent, rather anteriorly directed, projecting above the hinge-line and more or less strongly bent over it. The anterior ear is rounded and arched. A narrow sulcus or furrow in some examples passes from in front of and below the beak to the lower posterior margin, which is generally somewhat produced. In some examples the surface is almost smooth, except for very faint, close-set, rather foliaceous growth-lines. In others these are more prominent and widely spaced, while radial ridges may be prominently developed, giving a reticulated ornamentation to a part or all of the shell-surface. The shell of both valves in larger examples becomes wavy and irregular towards the lower and posterior margin. The surface of the right valve is sometimes rather arched, but generally well-rounded; the anterior auricle is well developed, and the beak small. Growth-lines are more or less widely spaced and irregular; but the radial ridges are generally weak, giving a faintly reticulated ornament to part of the surface.

Dimensions.—Left valve: height=21–27 mm., length=16–22 mm.; depth=10–15 mm. Right valve: height=20–22 mm.; length=20 mm.; depth=6–8 mm.

Locality.—Kohai Point, Kawhia, in calcareous shales with *Inoceramus haasti*; Oxfordian, or rather later. Several examples, both complete and broken, were collected.

Remarks.—The specimens are individually very variable, suggesting distinct species. The differences, however, result from the degree of inflation and arching of the beaks, the absence or presence of a furrow on the left valve, and the degree of foliation of the growth-lines and strength of the radial ribs with consequent reticulation of the surface. Any attempt to apply varietal names to a series of these shells would only lead to an unnecessary multiplication of trivial terms.

A comparison of this species with *Aucella hughendensis* R. Etheridge fil.,[2] of which I possess a slab with numerous specimens from Hughenden (Queensland), has been made, but the two forms do not seem to be closely related. The left valve of the Australian species is more strongly arcuate, and, although it bears a reticulate ornamentation, the species seems to be a much less variable one.

[1] J. F. Pompeckj, 'Aucellen im Fränkischen Jura' Neues Jahrb. vol. i (1901) p. 32; 'Ueber Aucellen & Aucellen-ähnliche Formen' *ibid.* Beilage-Band xiv (1901) p. 319.

[2] 'Geology & Palæontology of Queensland' 1892, p. 460 & pl. xxv, figs. 1–6.

Aucella spitiensis cf. var. extensa Holdhaus. (Pl. XIV, figs. 5 & 6.)

1913. 'Fauna of the Spiti Shales (Lamellibranchiata & Gasteropoda)' Pal. Ind. ser. 15, vol. iv, p. 408 & pl. xcvii, figs. 7-13.

Description.—Outline elongate oval, not very oblique. The beak is very anteriorly situated, almost terminal, strongly arched and rounded, in some examples nearly hemispherical, slightly bent over the hinge-line. The anterior umbonal portion of the valve is rounded and swollen, but towards the posterior and lower part it becomes flattened out. The surface is irregular, and bears several wide and shallow irregular concentric furrows, especially noticeable on the flatter parts. A broad depression occurs below the beak, some little distance from the lower anterior margin. The hinge-margin is straight or slightly bent, and the lower margin runs almost parallel with it; the posterior margin is well rounded, the anterior narrowly rounded; growth-lines are irregular, but well marked. The right valve is much flatter than the left, but is still well rounded; the beak is not generally raised above the surface of the valve, and traces of a small anterior ear are perceptible below it. The surface is marked with irregular, shallow, concentric growth-furrows. The shell in both valves is thin, and platy in structure.

Dimensions.—Left valve: length=52 mm.; height=20 mm.; depth=15 mm. Right valve: length=51 mm.; height=20 mm.

Locality and horizon.—Waikato, South Heads (North Island). Several examples were collected by Prof. P. Marshall and Mr. J. A. Bartrum. Upper Jurassic.

Remarks.—The left valve agrees closely with Holdhaus's pl. xcvii, fig. 12 *a*. The right valve, although more elongated, bears comparison with fig. 9.

Aucella spitiensis cf. 'forma typica.' (Pl. XIV, fig. 7.)

Description.—In the left valve the beak is anterior, but not quite terminal, not very prominent, rounded, and only slightly bent over the hinge-area. The hinge-margin is very slightly arched, the posterior margin broadly rounded (almost semicircular), the lower anterior margin gently curved, the anterior margin narrowly rounded. The whole surface of the shell is gently rounded, and is not marked by any irregular concentric furrows, except a very shallow scarcely perceptible one, almost midway from the beak to the lower anterior margin.

The left valve is decorated with a number of prominent, irregularly-spaced, rather wavy growth-ridges, which become distinctly foliaceous. They are widest apart in the umbonal region, but become rather crowded together towards the margins, and enclose shallow sulci between them.

The right valve is raised and rather flattened towards the beak, but becomes nearly flat posteriorly. It agrees in ornamentation

with the left valve, although the beak is less swollen and does not project above the hinge-margin. Owing to the damage to the beak, the ear of the right valve cannot be seen. The shell is thin, but its structure is not ascertainable, as it has been replaced by hæmatitic material.

Dimensions.—Length=57 mm.; height at the beak=25 mm.; towards the posterior margin=31 mm. Thickness of valves =20 mm.

Locality.—Waikato, South Heads. A specimen with both valves in apposition, the umbones rather damaged.

Remarks.—The specimen just described differs from *A. spitiensis* var. *extensa* in the more regularly rounded surface of the left valve, the less swollen and less arched beak, the fact that the shell broadens out posteriorly more rapidly, and in the possession of foliaceous growth-ridges. It seems to agree nearly, though not exactly, with the left valve shown in Holdhaus, pl. xcvii, fig. 8, although in that specimen the beak seems to be more anterior, and the outline to widen out more rapidly.

If one had only the New Zealand material to deal with, one might feel inclined to place these two *Aucellæ* in different species; but, from a study of the forms of *Aucella* described as *A. spitiensis*, it would appear to be unnecessary to do so.

Dr. Karl Holdhaus describes three 'varieties' of *A. spitiensis*, in addition to the typical form, namely, vars. *extensa*, *grandis*, and *superba*, which he unites as 'synchronous variations of a single species'. I have very little doubt that the elongate *Aucellæ* from Waikato are referable to the Himalayan species of the Spiti Shales. Two other species from Spiti are described in the same memoir: namely, *A. leguminosa* Stoliczka and *A. blanfordiana* Stoliczka, and it is remarked that both *A. leguminosa* and *A. spitiensis* are related to *A. bronni* Rouillier, but are at the same time perfectly distinct; while *A. blanfordiana* is closely related to *A. pallasi* Keyserling. In Russia a considerable vertical interval separates *A. bronni* from its derivative, *A. pallasi*, but the Indian specimens were not collected with sufficient care to show whether a series of derivative mutations is represented by them.

The Himalayan *Aucellæ* seem to yield little information of value in establishing the age of the beds, except that they are Upper Jurassic. Holdhaus says that a few of the occurrences point to an Upper Jurassic age as the most probable one for the Spiti Shales: for instance, certain species of *Aucella* the nearest allies of which are the European forms *A. bronni* and *A. pallasi*, and also a *Trigonia* closely allied to several species from the Jurassic of Kach (Chari Group).

Among some *Aucellæ* recently collected by Mr. J. A. Bartrum at South Heads, Waikato, and kindly sent to me, are two left valves and a right valve of a form indistinguishable from *A. blanfordiana*. They bear a close resemblance to the form figured by Holdhaus, pl. xcviii, figs. 3 *a*–3 *b* & 4 *a*–4 *b*. The

remainder mostly resemble *A. spitiensis* var. *extensa* figured in this paper. One of them bears a fossil attached to it that seems to be identical with *Placunopsis striatula* Zittel.

AUCELLA (?) MARSHALLI, sp. nov. (Pl. XIV, figs. 2–4.)

Description.—Both valves are approximately equal in size and degree of inflation, although the left seems to be slightly the larger of the two. In the left valve, which is well inflated, the beak is rather anteriorly situated, pointed, and projects above the hinge-line. The hinge-line behind the beak is concave; the hinder margin is produced, more or less rostrate, and rounded in outline; the lower margin is rather concave, the lower anterior margin rounded, and the anterior margin gently rounded. The surface of the shell is rounded, and has a more or less prominent ridge, which passes from behind the beak to the upper posterior margin, between which and the posterior hinge-line there is generally a concave areal surface. The surface of the shell is smooth, and bears a few narrow irregularly-spaced growth-furrows.

The right valve is moderately inflated, the beak rather anterior, pointed, and projecting above the hinge-line. The anterior margin is gently rounded, the lower slightly concave; the posterior margin is narrowly rounded and rather rostrate, the upper posterior margin gently concave. There is a small anterior ear with a deep byssal notch below it. The surface of the shell generally bears a broad shallow median sulcus, and is smooth (except for finely set growth-lines and occasional irregular growth-furrows). The shell is thin and platy in structure.

Dimensions.—A left valve measures in length 37 mm.; height=24 mm.; depth=13 mm. A right valve in length =31 mm.; height=24 mm.; depth=8 mm.

Locality.—Five specimens comprising three separate left valves, one right valve, and one with both valves conjoined but rather crushed, were collected by Prof. P. Marshall north of Sandy Bay, half-a-mile south-west of Roaring Bay, south of Nugget Point in the South Island. All are from a bed about 3 to 4 feet thick near the middle of the Jurassic sequence. A cast of both valves, rather distorted, 25 mm. long, comes from Kawhia Harbour; but the exact locality of it is, unfortunately, lost.

Remarks.—These shells belong to an apparently edentulous bivalve the characters of which are sufficiently obscure; but it seems to be attributable provisionally to the genus *Aucella*, on account of the platy structure of the shell and the presence of an auricle in the right valve. The characters of the shape, however, are not those of *Aucella*, and it is probable that it belongs to a new and undescribed genus which may be rather distantly related to a new genus *Hokonuia* that I described recently from the Carnic Beds of the New Zealand Trias. The specimens, however, with one or two exceptions, are distorted by crushing, so it

seems undesirable at present to found a new genus until more material is forthcoming.

It seems to be individually variable, as are so many of the bivalves in the Trias and Jura of New Zealand, as regards position of the beaks, development of the posterior concave area and of the sulcus on the surface of the shell, and in the degree of inflation of the valves.

'PSEUDOMONOTIS' MARSHALLI, sp. nov. (Pl. XV, figs. 6–9.)

Description.—Shell thin, elongate, roughly oval in outline. Beak of the left valve small, situated about the middle of the hinge-line, and only projecting slightly above it, the hinge-line being straight or slightly curved. Behind the beak is an obtusely angular wing, the outline of which in some specimens is scarcely differentiated from that of the shell-margin. The wing is devoid of radiating ribs, but the concentric growth-ripples pass over it. The lower posterior margin of the shell is produced, and is broadly though well rounded. The lower margin is gently rounded, while the anterior margin is produced and narrows somewhat, but is well rounded. The surface of the left valve is gently rounded; that of the right valve is flatter, though still rounded.

Numerous even and equidistant rounded ribs start from the beak, and pass to the margins. At varying distances from the beak secondary ribs are intercalated which pass to the margins, but do not always attain the strength of the primary ribs. Seventy-five ribs were counted round the margin of one specimen. Towards the posterior wing and the posterior hinge-area the ribs become weaker, and finally disappear. They are widest and most prominent on the anterior portion of the valves, and gradually decrease in size posteriorly. Growth-ripples occur near the beak, and rather widely and irregularly spaced concentric ridges occur on the body of the shell, tending to cut the ribs up into nodes.

The beak of the right valve does not project appreciably above the hinge-line.

Dimensions.—The left valve (fig. 6) is 50 mm. long and 30 mm. high.

Locality and horizon.—The slopes of Flag Hill in the Hokonui Hills, in a fine-grained yellow sandstone. Callovian (?). Several specimens of all sizes were collected, both left and right valves.

Remarks.—Sir James Hector[1] illustrates a left valve of this shell, calling it '*Pholadomya (?)*'. I can find no described species resembling this form. Its rounded outline differentiates it strongly from the species of *Pseudomonotis* that occur in the New Zealand Trias; but, in the present state of nomenclature, it must apparently be ranged under that generic name.

[1] 'Catal. Ind. & Col. Exhibition' 1886, p. 69.

PSEUDOMONOTIS cf. ECHINATA Sowerby. (Pl. XIII, figs. 14 & 15.)

Description.—Left valve swollen, about as wide as high, the lower and posterior margins rounded. Numerous fine ribs start from the beak, and pass to the margins; they are cut by the growth-lines into very small foliaceous nodes. The posterior wing is wide and rather flattened, the anterior less so. The right valve is subcircular in outline, rather longer than high, the posterior wing flattened, while the surface is well rounded and apparently smooth.

Dimensions.—Left valve=10 mm. in length and nearly 10 mm. in height. Right valve=8 mm. in length and 7 mm. in height.

Locality.—A slab of sandstone, with casts of both valves on it from which gutta-percha squeezes were made, comes from the stretch of coast between Nugget Point and the Catlins River. The exact locality is not stated: but the locality-number is 801, and the specimen belongs to the New Zealand Geological Survey.

Remarks.—This shell is very nearly related to, if not identical with, the well-known European Lower Oolite form. On comparing the squeezes with a number of specimens from the Cornbrash of Wiltshire in my collection, I can find no important points of difference. If it is identical, it forms an interesting instance of extended distribution of a common shell, the more so as some palæontologists hold the view that a form allied to this shell was the ancestor of the *Aucellæ*.[1] It has been recorded from the marine Jurassic of Western Australia.

OXYTOMA sp. (Pl. XII, fig. 9.)

Description.—Shell small, inflated especially in the umbonal region; the beak scarcely projects above the hinge-line, which is straight and prolonged into an acute posterior wing. There is a small anterior wing in front of the beak; the anterior margin is nearly straight, the lower is rounded, and the posterior margin rather produced. The decoration consists of about 24 straight or very slightly curved radial ribs, which do not seem to continue to the beak.

Dimensions.—Length=13 mm; height=11 mm.

Locality.—Junction of Taylor's Creek and the Otapiri. *Psiloceras* Beds.

Remarks.—This small aviculoid shell rather resembles in outline and ornamentation *Pseudomonotis münsteri* Bronn, of which a left valve is figured by Gottsche from Espinazito. *P. münsteri* is, however, a Lower Oolite shell, while the present example, a left valve, is from the lowest Lias. The ribs in the present shell seem, however, to be smaller and more numerous.

[1] J. F. Pompeckj, 'Ueber Aucellen & Aucellen-ähnliche Formen' Neues Jahrb. Beilage-Band xiv (1901) p. 337.

OXYTOMA sp. (Pl. XII, figs. 6 & 7.)

Description.—The beak of the left valve is situated about the anterior fourth of the hinge-line, and projects very slightly above it; the hinge-line is straight, the posterior wing is sharply prolonged, the anterior wing does not project beyond the lower anterior margin of the shell. The posterior margin is hollowed out below the wing, the lower margin is rounded. Four strong sharp raised ridges diverge from the beak and pass to the margins, one to the middle of the posterior margin, another, the strongest, to the lower margin beyond which it is prolonged into a finger-like process, and the other two, slightly curved, to the anterior margin. Between the main ribs the surface of the shell is decorated with very numerous close-set radial ribs; on the anterior and posterior portion of the shell these are all very even and small, but on the median part some of them are rather larger and more prominent than the rest. Growth-furrows occur at irregular intervals. The right valve is rounded in outline, considerably smaller than the left, and is nearly flat. It has a small and slightly raised beak which does not project above the hinge-line, and in front of it there is a small rounded anterior auricle with an angular indentation below it. The radial ribs correspond with those of the left valve, but are faintly marked and do not seem to be prolonged much beyond the margin of the valve.

Dimensions.—Left valve: length=24 mm.; height=21 mm. Right valve: length and height=about 13 mm.

Locality.—Junction of Taylor's Creek and the Otapiri; *Psiloceras* Beds. An impression of a left valve from which a gutta-percha squeeze was made is illustrated in fig. 6. Another specimen consists of a left valve partly broken away, showing the right valve in position (fig. 7).

Remarks.—The left valve bears a close resemblance to the young portion of a specimen of *O. cygnipes* Young & Bird from the Middle Lias of Market Harborough (Leicestershire). I hesitate, however, to identify it with this well-known species, because of its occurrence in New Zealand with ammonites of the lowest Lias, and because in one of the New Zealand specimens the right valve is much smaller than the left; whereas, in the above-mentioned English form, the right valve seems to be about equal in area to the left, and to have similarly prolonged ribs.

OXYTOMA sp. (Pl. XII, fig. 8.)

Description.—The beak is anteriorly situated, and is well differentiated from the rest of the shell. It is narrow and inflated, and projects slightly above the straight hinge-line. There is a blunt rather flat posterior wing, with a slight marginal excavation below it. The lower posterior margin is slightly produced, the lower margin gently rounded and somewhat produced, the anterior margin gently rounded, and there is a small anterior wing. The inflated beak merges gradually into the surface of the

shell, which becomes rather flattened towards the margins, but slopes steeply down to the posterior wing (which is devoid of ribs). About fifteen radial ribs are present, which become rather stronger and are gently curved on the anterior part.

Dimensions.—Length = 24 mm.; height = 21 mm.

Locality.—Junction of Taylor's Creek and the Otapiri, Hokonui Hills. *Psiloceras* Beds.

Remarks.—The only specimen is a left valve with the shell dissolved away. Other less perfect casts and impressions may belong to the same form, but the condition of the material makes it undesirable to attach a specific name to it. It seems to bear some resemblance to a form described from Cretaceo-Jurassic deposits of Queensland as *O. rockwoodensis* R. Etheridge fil.[1]

OXYTOMA sp. (Pl. XIII, fig. 10.)

Description.—A single left valve is gently and regularly rounded, especially in the umbonal region. The beak is anterior, and projects very slightly above the straight hinge-line. Behind it there is a prolonged angular wing, well differentiated from the rest of the shell. Below the wing the posterior margin of the shell is considerably produced. The lower margin is gently rounded, and the anterior margin is also gently rounded with hardly any trace of an anterior projection. The ornamentation consists of about eleven radial ribs that start from the umbo and pass to the margins, where they are continued as short blunt prolongations. All the ribs are rounded and rather faint, some more so than others, and they are smaller and closer together on the anterior than on the posterior portion of the shell. Very faint radial ribs are intercalated between the main ribs.

Dimensions.—Length = 34 mm.; length of hinge-area = 23 mm.; height = 26 mm.

Locality.—Southern shore of Kawhia Harbour, probably Totara Point.

Remarks.—It is useless to burden nomenclature with new specific names for these shells. This valve,[2] which belongs to the New Zealand Geological Survey, bears comparison with *Avicula costata* Sowerby, a Bathonian species, of which Gottsche[3] figures two casts of two left valves from Espinazito in the Andean Cordillera. The beak in the New Zealand specimen is more anterior than in either of Gottsche's figures, but this seems to be a variable feature.

PTERIA cf. CONTORTA Portlock. (Pl. XII, fig. 10.)

1843. 'Report on the Geology of Londonderry' p. 126 & pl. xxv A, fig. 16.

Description.—A single left valve, preserved as an internal cast

[1] 'Geology & Palæontology of Queensland' 1892, p. 448 & pl. xxiv, fig. 15.

[2] It is apparently the original of a figure in J. Hector, 'Catal. Ind. & Col. Exhibition' 1886, p. 69, labelled '*Avicula cynipes* [sic] var.'

[3] 'Jura-Versteinerungen aus der Argentinischen Cordillera' Palæontographica. Suppl. iii (1878) pl. vi, figs. 16 & 17.

in a gritty felspathic conglomerate. The beak projects well above the hinge-line, and is anteriorly situated. The hinge-line is straight, produced, and pointed behind. The anterior and lower posterior margins consist of one almost semicircular curve. The shell is somewhat produced behind; the valve is well swollen, but flattens out posteriorly. The primary ribs commence at the beak; about twelve ribs are visible, round the margin, each alternate one of which seems to begin about half-way from the beak.

Dimensions.—Length = 15 mm.: height = 13 mm.

Locality.—'*Trigonia*' Beds, slopes of the South Peak, Benmore (Hokonui Hills), in beds said to be of Rhætic age. Collected by A. McKay in 1878.

Remarks.—Having only a single left valve, I cannot be certain as to the species of this shell; but it is strongly reminiscent of some specimens of the familiar *Pteria contorta.* The ribs are not quite so numerous as in most examples, and the shell is not so narrow: that is, the posterior margin does not appear to follow the semicircular outline of the anterior and lower margin, as it does in typical specimens of *Pt. contorta.*

However, it seems to belong to that group, and the occurrence of a series of beds with *Pt. contorta* in New Zealand is not improbable, since they have been traced in Upper Burma. The specimen now described is not unlike an internal cast of a left valve figured from that district.[1]

INOCERAMUS cf. GALOI G. Bœhm. (Pl. XV, figs. 1 & 2.)

1907. 'Die Südkusten der Sula-Inseln Taliabu & Mangoli' p. 68 & pl. ix, figs. 10–14, pl. x, figs. 1 *a*–1 *c*, 2.

Description. — Shell subtriangular in outline, elongate, tapering gradually; the beaks are very anterior, sharp, pointed, and produced. The hinge-line is very gently curved, and seems to have occupied rather more than a third of the length of the shell. The posterior margin of the shell is gently curved, the lower or hinder margin rounded and nearly semicircular, the anterior margin below the beak straight or slightly concave. In the neighbourhood of the beaks the shell is somewhat arched and swollen, but flattens out towards the hinder margin. The hinge-margin makes an angle of about 40° with the anterior margin. In my specimens neither the test nor the ligament-pits are well seen.

Dimensions.—Length from beak to lower margin = about 100 mm.; greatest width = about 49 mm.

Locality.—Totara Point, Kawhia, where the shells are rather common in the fine-grained glauconitic sandstones. Prof. Marshall sends me a specimen from Kerrs, south-west of Nugget Point, in the south-east of the South Island, in a similar matrix.

Remarks.—The *Inocerami* at Totara Point differ from the

[1] Maud Healey, 'Fauna of the Napeng Beds' Pal. Ind. vol. ii, No. 4 (1908) pl. v, fig. 8.

typical specimens of *Inoceramus haasti* at Kohai Point in being more elongate and narrower, and having much more acute beaks and more numerous concentric ribs, which are about equal in width to the furrows between them.

The form now described occurs on a lower horizon than *I. haasti*, of which it may be an ancestor. There are two specimens in my collection, and one from Kerrs belonging to Prof. Marshall. They bear a close resemblance to Bœhm's figures (pl. ix, fig. 12 & pl. x, fig. 1). His description of the species was drawn up from 115 specimens which he collected on the Wai Galo, where he describes the river-bed as being paved with them, specimens of various sizes occurring in clay-limestone nodules.

He remarks that the species is reminiscent of *I. retrorsus* Keyserling; but he makes no mention of any resemblance to the New Zealand shell *I. haasti*. He figures two other species: namely, *I. taliabuticus* Bœhm and *I. sularum* Bœhm, from the same locality; but in both of these the angle between the hinge and the anterior margin is much greater than it is in either *I. galoi* or *I. haasti*. Bœhm's figure of *I. galoi* (pl. ix, fig. 14), in the width of its shell and the wide spacing of the sharp concentric ribs, is very reminiscent of a small specimen of *I. haasti*.

INOCERAMUS HAASTI Hochstetter. (Pl. XV, fig. 3.)

K. A. von Zittel, 'Paläontologie von Neu-Seeland' 1864, p. 33 & pl. viii, figs. 5 *a*–5 *c*.

Description.—Outline subtriangular, the hinder and lower margins well rounded, the anterior margin rather concave. The beaks are pointed, slightly rolled, and the shell in the neighbourhood of the beaks is well inflated. The ornamentation consists of seven or eight coarse concentric ribs, rather irregularly spaced, especially towards the margins, the interspaces being strongly hollowed out. On the young shell the ribs are low and rounded, and not at all sharp or prominent, but increase after the shell has attained a length of about 25 mm.

Dimensions.—Length = about 106 mm.; greatest width = about 62 mm.

Locality.—Kohai Point, Kawhia, with *Aucellæ* of the group represented in Pl. XVII, figs. 4–8, called *A. plicata* Bœhm.

Remarks.—Zittel, whose specimens are recorded from Takatahi, east of Kohai Point, says that only very incompletely preserved casts were at hand, and therefore no determination could be made with certainty. The whole surface was ornamented with very strong concentric folds which spring rather strongly forwards. The shape reminded him very much of *I. crippsi* and other related forms from the European Cretaceous. Bœhm, who had 22 specimens which were collected for him by the late Mr. H. Suter at Kohai Point and southwards, and between Captain King and Totara Point, remarks that the form is triangular, and therefore can bear no relation to *I. crippsi*. His largest specimen was from

the last locality, was 18 cm. long and 10·5 wide, and had attached to it *Aucella plicata*, several *Rhynchonellæ*, and a fragment of a belemnite.

My experience is that the *Inocerami* at Totara Point are very much more like *I. galoi* than are the specimens of *I. haasti* from Kohai Point, although, as I have previously remarked, one of Bœhm's figures of *I. galoi* is very like a small *I. haasti*.

Pecten (Camptonectes) cf. lens J. Sowerby. (Pl. XIII, fig. 11.)

Description.—The beak of the left and convex valve is small, and projects rather above the hinge-area. The surface of the shell is rather strongly arched in the region of the beak, but becomes gently rounded towards the margins. The right valve is much flatter than the left, and the beak less prominent. The surface of the left valve is decorated with fine radial ribs which diverge from a median line, and sweep regularly with a gentle curve towards the anterior and posterior margins. About the median line they tend to become wavy, the waviness being most pronounced from about the middle of the shell to the lower margin. The ribs cover the whole surface of the convex valve, and the fine closely-set growth-lines tend to cut them up into a series of very small nodes. Larger interruptions of growth occur at varying intervals. The ornamentation of the right valve is similar but less pronounced, and parts of the shell about the beak and median line are almost smooth.

Dimensions.—Length=about 39 mm.; height=40 mm.

Locality.—Totara Point, Kawhia; one specimen with part of both valves (unfortunately rather damaged round the margin and wings), and another imperfect right valve.

Remarks.—This shell belongs to the group of *P. lens*, but its fragmentary condition forbids an exact specific determination. Several Pectens of this group are recorded from Puente del Inca and Espinazito in the Argentine Cordillera.[1] *P. laminatus* Sowerby occurs at Espinazito.

Pecten (Syncyclonema) sp. (Pl. XV, fig. 4.)

Description.—Shell rather thick, subcircular in outline, depressed, beak small; the ears are small, approximately equal in size, their outer borders curving slightly downwards from the beak, the extremities somewhat raised. The shell-surface is gently rounded and smooth, with one prominent growth-interruption and other faint growth-lines which are visible also on the ears.

Dimensions.—Length=20 mm.; height=20 mm.

Locality.—Flag Hill, Hokonui Hills. Callovian (?).

Remarks.—Only one valve has been obtained, probably a left valve; the drawing was made from a gutta-percha squeeze. This shell seems to belong to the group of *P. demissus* Phillips.

[1] C. Gottsche, 'Ueber Jura-Versteinerungen aus der Argentinischen Cordillera' Palæontographica, Suppl. iii (1878) p. 40 & pl. v, fig. 16, &c.

A poorly-preserved *Pecten*, which may belong to this genus, occurs in the *Psiloceras* Beds at Taylor's Creek, in the Hokonui Hills.

PLEUROMYA sp.

Description.—Shell thin, beaks almost anterior, anteriorly directed, tapering rapidly, close together and rather inrolled. There is a sunken area in front and below the beak, and behind it the hinge-area is much sunken. The lower margin is nearly straight, the lower anterior margin is bluntly rectangular and projects beyond the beak, the front margin is gently concave. The shell is seemingly closed all round, presumably edentulous, and seems slightly inequivalve, the left valve being apparently somewhat the larger. The surface is decorated with fine growth-lines, and the whole surface is more or less irregularly furrowed concentrically, some specimens much more so than others.

Dimensions.—Length = about 50 mm.; height = 35 mm.; diameter of both valves = 30 mm. Another specimen is 40 mm. long, 30 mm. high, and 25 mm. in diameter.

Locality.—Totara Point, Kawhia.

Remarks.—Several specimens of this *Pleuromya*-like shell were collected. The whole series seems to belong to one species, despite the individual variation that has been mentioned. They are much crushed in various directions and otherwise damaged, and therefore it is not advisable to make any specific determination. One of them recalls somewhat a shell called '*Mactromya (?)* sp.,' which Gottsche figures from the Lower Oolite of Espinazito, in the Argentine Cordillera.[1]

TRIGONIA KAWHIANA, sp. nov. (Pl. XIII, figs. 6–9.)

Description.—Beaks anteriorly situated, not very prominent, flattened and compressed. The anterior margin slopes rapidly down from the beaks and is gently rounded, the lower margin is gently rounded, the posterior broadly rostrate and rather angulate below. The areal margin behind the beaks is rather concave. A slightly raised rounded ridge cut by the growth-lines into foliaceous nodes sweeps from behind the beak to the lower posterior margin, separating the shell into an anterior gently rounded portion and a flatter posterior areal portion. The latter has a faint furrow passing down it, situated rather nearer to the areal margin than to the ridge. The posterior surface is decorated with fine, rather closely-set, equidistant, foliaceous growth-ridges.

The main anterior part of the shell is ornamented with nine or ten primary ribs that radiate downwards from the region of the beak and from the anterior side of the ridge. These large primary ribs are confined to the posterior part of the shell in front of the ridge behind and below the beak, and only the last three or four of them continue to the lower margin. In front of the beak another series of finer but rather sharp raised ribs pass from the

[1] *Op. cit.* p. 33 & pl. vii, fig. 3.

anterior margin downwards and backwards; where they meet the larger ribs they form an acutely angular V-shaped decoration, which is specially marked in that part of the shell that lies just below and behind the beak.

All the ribs are more or less cut by the growth-lines, which are sharp and regular, forming a finely nodose ornamentation in front of the primary ribs in the lower half of the valve. The nodes often conjoin, and become elongated in the direction of the growth-lines. Nothing of the dentition could be seen.

Dimensions.—Length = 21 mm.; height = 18 mm.; another specimen is 18 mm. long and 12 mm. high.

Locality and horizon.—Southern shore, Kawhia Harbour. All the specimens belong to the New Zealand Geological Survey.

I did not find any; but, as several species of fossils that Prof. Marshall and I collected at Totara Point occur in the same pieces of rock with them and the matrix is similar, it seems that these Trigonias are from some exposure at or very near Totara Point.

Remarks.—These Trigonias generally are poorly preserved; but, by dissolving the shell with weak acid from the cavities in the fine-grained greywacke, and making gutta-percha squeezes, one can recover the rather complicated surface-ornamentation.

They belong to a group of which several forms have been described from the Bathonian and Lower Oolite of Espinazito in the Argentine Cordillera. These are *Trigonia prælonga* Gottsche; *T. rectangularis* Gottsche; *T. lycetti* Gottsche; *T. signata* Agassiz[1]; *T. exotica* Steinmann; and *T. gottschei* Möricke.[2]

The New Zealand form is rather similar in some ways to *T. lycetti* from the Lower Oolite of Espinazito, but is much smaller than the largest specimens of that species, which has two furrows on the areal region. The nature of the ribs that spring from the main ridge also is different.

In shape it rather resembles *T. exotica*; but the number of ribs in that species is less, they are broken up into larger nodes, and the V-shaped decoration is less strongly marked.

The South American form which it most closely resembles in ornament is *T. gottschei*; but that is a very much more elongate shell, and has two furrows passing down the area as in *T. lycetti*, while the shell here described has only one.

T. rectangularis is a shell that agrees in general size and outline with the New Zealand form; but the decoration is much simpler, and the V-shaped costation is much less acutely angular, being practically a right angle.

The decoration of all these Trigonias refers them to the group of the Undulatæ, of which two of the best-known members are *T. literata* Young & Bird, from the *jurensis* zone of Yorkshire,

[1] C. Gottsche, 'Ueber Jura-Versteinerungen aus der Argentinischen Cordillera' Palæontographica, Suppl. iii (1878) pp. 24–27 & pl. vi.

[2] W. Möricke, 'Versteinerungen des Lias & Unteroolith von Chile' Neues Jahrb. 1894, pl. vi, figs. 7–9.

and *T. V-costata* Morris & Lycett of the 'Lower Oolite.' Gottsche records the similarity of *T. lycetti* to *T. V-costata*.

Hector's '*Trigonia navis* var.'[1] is apparently intended to represent the shell now described.

Astarte.

Dr. Karl Holdhaus recorded and described four species of *Astarte* from the Spiti Shales.[2] These are *A. hermanni* Oppel, *A. sowerbyana* Holdhaus, *A. scytalis* Holdhaus, and *A. spitiensis* Stoliczka. The first two are very similar one to the other, and the last is said to be distinguished from them by its shell being higher and having a more rounded outline.

Holdhaus remarks that these Spiti species of *Astarte* are not clearly related to any extra-Indian forms, and, owing to his lack of opportunity of examining the specimens, it is uncertain whether or not *A. hermanni* and *A. sowerbyana* may be identical with *A. unilateralis* Sowerby and *A. minor* Sowerby from Kach. By comparison with Sowerby's illustrations, however, it is suggested that this may be so.

Several Astartes that I collected at Totara Point undoubtedly belong to this group; but, owing to the fact that, except in two or three instances, the shell is broken round the edges, an absolutely certain specific attribution is not advisable.

Astarte spitiensis Stoliczka. (Pl. XIII, figs. 1 *a* & 1 *b*.)

1866. Mem. Geol. Surv. India, vol. v, p. 91 & pl. ix, fig. 9.
1913. K. Holdhaus, 'Fauna of the Spiti Shales (Lamellibranchiata & Gasteropoda)' Pal. Ind. ser. 15, vol. iv, pt. ii, fasc. 4, p. 444 & pl. c, figs. 4–8.

Description.—Beaks anteriorly situated, small, projecting considerably above the hinge-line. The latter is very slightly curved, and occupies about two-thirds of the length of the shell. The upper posterior margin is bluntly angular, the posterior margin gently rounded, the lower margin well rounded, the anterior margin rather produced and rounded. In front of and below the beak is a sunken heart-shaped lunule, forming a rounded excavation that extends over less than a quarter of the height of the shell. The surface of the shell near the umbones is rather flattened, the flattening extending nearly to the level of the lower part of the lunule. The flattened part is decorated with more or less equidistant, prominent, and rather foliaceous growth-lines. Below this the surface is gently rounded, and has a very faint angulation extending from behind the beak to the lower posterior margin. It is decorated with closely but irregularly set growth-lines which vary in strength. On the posterior part between the angulation and the hinge-line they are very closely set and rather

[1] 'Catal. Ind. & Col. Exhib.' 1886, p. 69, fig. 3.

[2] 'Fauna of the Spiti Shales (Lamellibranchiata & Gasteropoda)' Pal. Ind. ser. 15, vol. iv, pt. ii, fasc. 4 (1913) p. 440 & pls. xcix–c.

foliaceous, but are much weaker than on the flattened part below the beaks.

Dimensions.—Length=52 mm.; height=45 mm.; diameter of both valves=27 mm.

Locality.—Totara Point, Kawhia.

Remarks.—This shell agrees closely in outline and ornamentation with *A. spitiensis* (especially Holdhaus, pl. c, fig. 4 *a*), and I have scarcely any doubt that it is specifically identical.

ASTARTE cf. SOWERBYANA Holdhaus. (Pl. XIII, fig. 2.)

1913. 'Fauna of the Spiti Shales (Lamellibranchiata & Gasteropoda)' Pal. Ind. ser. 15, vol. iv, pt. ii, fasc. 4, p. 443 & pl. xcix, figs. 12, 13, 15, pl. c, fig. 1.

Description.—This shell agrees in general features with that just described, but is smaller and has been apparently more elongate; the surface is more rounded, and the portion below and adjacent to the beaks is less flattened. The hinge-margin posterior to the beaks seems rather more curved. The surface is covered with somewhat prominent irregularly-spaced growth-lines, which vary in strength.

Dimensions.—Length=46 mm.; height=35 mm.; diameter =25 mm.

Locality.—Totara Point, Kawhia.

Remarks.—This specimen seems to approach nearest to the species of Holdhaus, especially the specimen that he figures in pl. xcix, fig. 15 *a*. It may also be compared with a specimen of *Astarte hermanni* Oppel in the same plate, fig. 14 *a*.

ASTARTE cf. SCYTALIS Holdhaus. (Pl. XIII, fig. 3.)

1913. 'Fauna of the Spiti Shales (Lamellibranchiata & Gasteropoda)' *op. cit.* p. 444 & pl. c, figs. 2–3.

Description.—Shell elongated, surface gently rounded; the part below the beaks is hardly perceptibly flattened, but bears widely spaced and regular growth-lines. On the remaining surface of the shell the growth-lines are prominent, closely set, and irregular in strength.

Dimensions.—The specimen under description is much broken, but has been about 57 mm. long, 40 mm. high, and 24 mm. in diameter across the two valves.

Locality.—Totara Point, Kawhia.

Remarks.—This specimen, or what remains of it, closely recalls that figured by Dr. K. Holdhaus, pl. c, fig. 2 *a*.

ASTARTE (OPIS?) MORGANI, sp. nov. (Pl. XIII, figs. 4 *a*, 4 *b*, & 5.)

Description.—Shell thick; beaks prominent, pointed, tapering, close together, enclosing below them a deep, heart-shaped, lunular depression. A rather prominent, angular, blunt ridge commences behind the beak, and passes with a gentle curve to

the posterior lower margin, separating the shell-surface into two parts. That in front of the ridge is gently rounded, that behind it is somewhat flatter or gently curved. The posterior margin of the shell is obtusely angular, the lower margin is gently rounded, the anterior margin is rather produced, and is gently rounded below the lunule. The inner margin of the valves is somewhat deeply pitted or crenulated. The surface is decorated with fine, closely-set, rather foliaceous, concentric ribs, some of which are more prominent than others. The ribs continue across the ridge on to the posterior area, where they become somewhat sharper and more foliaceous.

Dimensions.—The shape is rather variable; some specimens are higher than others, and have a more prominent beak. One left valve is 28 mm. high, 24 mm. long, and 9 mm. deep. Another, with both valves in apposition, is 22 mm. high, 26 mm. long, and one valve is 7 mm. deep. Another imperfect right valve is 31 mm. long and of about the same height. They all, however, appear to represent one species.

Locality.—Totara Point, Kawhia, where specimens are rather common.

Remarks.—About eight specimens were collected. The cordiform aspect of the two valves when conjoined, and the deep lunule bordered by a rather sharp ridge suggest the genus *Opis* rather than *Astarte*. I cannot find any species described from the Spiti Shales or elsewhere that resembles it.

I have pleasure in naming this species after my friend, Mr. P. G. Morgan, the Director of the New Zealand Geological Survey.

(*d*) Brachiopoda.

RHYNCHONELLA sp. (Pl. XVI, figs. 8 *a* & 8 *b*.)

Description.—Shell subtrigonal in outline, about as wide as long. The beak is small, tapering, not bent over the dorsal umbo. Valves inflated, especially towards the anterior portion, the dorsal more so than the ventral. The dorsal valve has a short median fold which only continues for a short distance from the anterior margin, and on either side of it a similar but rather larger fold that continues about half-way to the beak. These folds enclose a rather shallow angular sinus on each side of the median fold, and this part of the shell towards the anterior margin is raised and flattened, and is bordered by steep slopes. The ventral valve has a short median sulcus bordered by two short rounded folds, on each side of which again is a shallow sulcus. All these occupy that part of the shell which borders the anterior margin. There is a broadly rounded fold on each side forming wing-like projections, and a broad, shallow, rounded, median fold which continues nearly to the beak. There are sharp dental plates in the ventral valve, and a short median septum in the dorsal valve.

Dimensions.—Length=19 mm.; width=20 mm.; thickness =10 mm.

Locality.—Lower slopes of Flag Hill, Hokonui Hills; in sandstone. Callovian (?).

Remarks.—One specimen, rather crushed laterally, consists of a cast, the test missing. Mr. Buckman writes that it has quite a remarkable likeness to *Rhynchonella funiculata* Deslongchamps of the Callovian.

RHYNCHONELLA sp. (Pl. XVI, figs. 9 & 10.)

Description.—Outline triangular or subpentagonal, wider than long. Valves fairly well inflated, the dorsal more so than the ventral, beaks small and tapering rapidly. The dorsal valve has a median raised and flattened anterior portion, upon which in one specimen are two, in another four folds, which continue nearly to the beak but become gradually weaker. There are two rounded lateral folds, which continue nearly to the beak. The ventral valve of one specimen has one, another has three median folds which continue to the beak, on each side of which are lateral rounded folds that pass about two-thirds of the way to the beak.

Dimensions.—Length=15 mm.; width=18 mm.; thickness =about 9 mm.

Locality.—Lower slopes of Flag Hill, Hokonui Hills; in sandstone. Callovian (?).

Remarks.—I have two internal casts, both a good deal crushed, which may belong to one species, although one has more and sharper median folds than the other. Mr. Buckman writes that they exhibit the general aspect of Callovian Rhynchonellæ, but the internal details (such as they are) differ. The New Zealand specimens show short dental plates doubtfully divergent, and a very short dorsal septum about a quarter of the length of the valve. Dr. F. L. Kitchin[1] describes a species, *Rh. pauciplicata*, as having well-developed dental lamellæ and a median dorsal septum about a third of the length of the dorsal valve. The specimen (fig. 9), if uncrushed, would resemble in general outline Dr. Kitchin's fig. 4; but in the Indian examples the ribs are developed only in the region of the frontal and lateral margins, while in the New Zealand examples they extend nearly to the beak.

RHYNCHONELLA sp. (Pl. XII, fig. 5.)

Description.—Shell subtriangular in outline, the sides sloping straight away from the ventral beak. The latter is slightly incurved, but the delthyrial region is hidden in the matrix of the specimen. Both valves are about equally inflated. On the ventral valve, which is gently rounded, there is a broad median sulcus which extends about half-way to the beak, and has five low angular folds on it which disappear or merge into the smaller ribs about half-way to the beak. Two angular folds appear on each

[1] 'Jurassic Fauna of Kutch: Brachiopoda' Pal. Ind. ser. 9, vol. iii, pt. i (1900) p. 70 & pl. xv, figs. 4, 5, 8.

side of the median depression, but these also disappear, as do the median folds. Fifteen or twenty very much smaller rounded ridges diverge from the beak; but, rather more than half-way to the anterior margin, they disappear, or become merged into the larger angular folds already mentioned.

Dimensions.—Length=12 mm.; width=15 mm.; thickness =7 mm.

Locality.—Junction of Taylor's Creek and the Otapiri. *Psiloceras* Beds.

Remarks.—Mr. S. S. Buckman writes, regarding the specimen that I submitted to him, that it is a Rhynchonellid with conjugate or rimosiform ribbing. Very few European Rhynchonellids are known from the Hettangian, and he doubts whether there are any with rimose pattern. The New Zealand form is quite distinct from the *Rh.-rimosa* Von Buch and *Rh.-furcillata* Theodori groups of the Charmouthian–Domerian.

RHYNCHONELLA (CRYPTORHYNCHIA) KAWHIANA, sp. nov. (Pl. XVI, figs. 1–3.)

Description.—Shell rather wider than long, valves inflated, the dorsal considerably more so than the ventral. The greatest convexity occurs about the middle of the dorsal valve. The beak is small, sharp, not prominent, and projects slightly beyond the ventral area; it is not much incurved, leaving an open delthyrium and foramen and a ventral area shorter than the width of the shell, striate parallel to the hinge-margin, with rather foliaceous lines. The dorsal valve is well and regularly rounded, and bordered by steep slopes. The ventral valve has a broad median sulcus with a broad fold on each side, all of which merge into the rounded surface of the valve. The surface of both valves is decorated with fine, regular, rounded ribs, all about equal in size, that diverge from the beaks. These are cut by the concentric growth-lines and are prolonged, especially towards the margins, into a number of solid spines. On one specimen completely detached from the rock (fig. 2) the spines are missing; on another (fig. 1) they are 4 mm. long; on a third (fig. 3), where the shell has been completely crushed and the spines preserved in the rock, one spine is 9 mm. long. There is a faint, short and sharp, dorsal median septum, apparently less than a quarter of the length of the valve.

Dimensions.—Length=14 mm.; width=17 mm.; thickness =11 mm. Another specimen is 18 mm. long, 22 mm. wide, and about 14 mm. thick.

Locality.—Totara Point, Kawhia.

Remarks.—The occurrence of a spiny *Rhynchonella* in New Zealand is rather remarkable, and on collecting it I was naturally reminded of the genus *Acanthothyris*. I am indebted to Mr. Buckman, however, for the suggestion that it is probably a spinous development of the Indian *Rhynchonella pulcherrima*

Kitchin,[1] or some closely-allied form. Dr. Kitchin, in a letter to Mr. Buckman, concurs with this suggestion.

One specimen (fig. 2) agrees in some respects with Kitchin's pl. xi, fig. 4; but, in the New Zealand specimen, the dorsal valve is regularly rounded, and not flattened towards the umbo as it is in *Rhynchonella pulcherrima.* The Indian form is confined to the upper beds of the Putchum Group (Bathonian), where it is said to occur in great profusion.

TEREBRATULA (KUTCHITHYRIS) cf. ACUTIPLICATA Kitchin. (Pl. XVI, figs. 5–7.)

1900. 'Jurassic Fauna of Kutch: Brachiopoda' Pal. Ind. ser. 9, vol. iii, pt. i, p. 6 & pl. i, figs. 1–7.

Description.—Outline subovoid or subpentagonal, in most specimens rather longer than wide, in others the length is equal to the width. The ventral and dorsal valves are about equally inflated, the dorsal sometimes rather more so than the ventral. Beak rounded, not very prominent, projecting slightly over the dorsal valve; the aperture encroaches on the umbo, almost concealing the delthyrium of the ventral valve. The dorsal valve has two prominent rather angular folds, which start from the anterior margin, and pass to about midway between the anterior margin and the beak, where they disappear in the rounded surface of the valve. They enclose a more or less deep sulcus, and are bounded by broad lateral sulci. On the ventral valve a median fold corresponds to the median sulcus of the opposite valve, with a broad sulcus on each side of it, and on each side of these is a rounded fold. All these folds and sulci disappear rather more than half-way from the anterior margin to the beak. Growth-lines are rather coarse and irregular at first, but become more prominent, regular, and closely set towards the anterior margin of fully-grown shells.

Dimensions.—Length=34 mm.; width=31 mm.; thickness =about 16 mm. Another specimen is 34 mm. long and wide, and about 21 mm. thick at the greatest diameter.

Locality.—Totara Point, Kawhia. I collected several specimens, some of which are more or less crushed and distorted, a process that often accentuates the folding of the shell.

Remarks.—Mr. Buckman writes, regarding three specimens that I submitted to him, that his genus *Kutchithyris*[2] is founded on Kitchin's species *Terebratula acutiplicata*, to which the New Zealand specimens have a most remarkable resemblance. He remarks that the short beak approximate to the umbo is characteristic of *Kutchithyris.* Most of the specimens of this anteriorly biplicate New Zealand shell resemble that figured by Dr. Kitchin in his pl. i, figs. 1–3. One specimen (fig. 6) is more acutely biplicate, a feature which does not seem to be entirely due to

[1] 'Jurassic Fauna of Kutch: Brachiopoda' Pal. Ind. ser. 9, vol. iii, pt. i (1900) p. 52 & pl. xi, figs. 1–9, 16.
[2] Rec. Geol. Surv. India, vol. xlv (1915) p. 78.

crushing, and it recalls in this respect Kitchin's fig. 6. In the Indian examples the ventral valve is said to be always more convex than the dorsal; but this does not seem to be the case with all the New Zealand specimens.

In Kutch this species is confined to the Upper Putchum Beds, where it occurs in great profusion.

TEREBRATULA (HEIMIA ?) sp. (Pl. XVI, figs. 4 *a* & 4 *b*.)

Description.—Outline ovoid, rather longer than wide. Beak not prominent, incurved but not bent over the dorsal umbo, although apparently it hides the delthyrium. The valves are about equally convex. Surface smooth, except for the growth-lines. The dorsal valve has its greatest convexity rather less than half-way from the anterior margin to the beak, and neither valve bears any plication; consequently the junction of the valves lies in one plane. Shell thin.

Dimensions.—Length=24 mm.; width=21 mm.; thickness =10 mm.

Locality.—Lower slopes of Flag Hill, Hokonui Hills. In sandstone. Callovian (?).

Remarks.—I have two specimens: that figured, and another one much elongated through crushing. Neither bears the test, but part of the impression remains in the rock. Mr. Buckman writes of the specimen, that it bears a considerable likeness to *T. planiconvexa* Kitchin [1]; but it is doubtful whether the New Zealand example has the necessary convexity of the ventral valve, although crushing may have destroyed this. *T. planiconvexa* occurs in the Upper Putchum Beds of Jumara in Kutch.

SPIRIFERINA (?) sp. (Pl. XVI, figs. 11 *a* & 11 *b*.)

Description.—The ventral valve is semipyramidal in shape, with a flat and high triangular area striated or grooved parallel to the hinge-line. The hinge-teeth are strong, and are supported by two strong dental plates, which seem to join the median septum; this is thin and sharp, and extends for about half the length of the ventral valve. The delthyrium is triangular and open. There is a faint, broad, shallow, median sulcus, and on each side of it are four or five faint ribs, which radiate from the beak to the anterior and lateral margins. The shell seems to have been thin, but is dissolved away, so one cannot ascertain whether its structure was punctate or not. The surface has two or three well-marked growth-interruptions, and was covered with spines, some rather large but most of them small, the impressions of which are seen with a lens on the mould. The dorsal valve is missing.

Dimensions.—One specimen, a ventral valve, is 6 mm. long, 11 mm. wide, and the area is 4 mm. high. Another larger specimen, the cast only of a ventral valve, is 14 mm. long and 20 mm. wide.

[1] 'Jurassic Fauna of Kutch: Brachiopoda' Pal. Ind. ser. 9, vol. iii, pt. i (1900) p. 15 & pl. iii, figs. 4–5.

Locality.—Slopes of Flag Hill, Hokonui Hills. Callovian (?).

Remarks.—This brachiopod is evidently a degenerate survivor of one of the Spiriferids of the Trias. Old-age features are apparent in its covering of spines, and we may note the fact that the arrangement of dental plates and median septum is of the Cyrtiniform character that is apparent in so many of the Spiriferinæ of the Alpine Rhætic, and of the New Zealand Trias. I have discussed this question in a paper dealing with the Triassic brachiopoda.[1]

Since the nature of the shell-structure and of the spiralia and the dorsal valve is unknown, it is perhaps of little use to enquire further to which of the Triassic forms it may be referred. No *Spiriferina* of the Trias that I know of bears spines. It may be related to the spiny shell, *Mentzeliopsis*, which is a spinous development of *Mentzelia*; in that form, however, the hinge-plates do not join the median septum, but lie alongside of it.

VIII. Appendix.—On Ammonites from New Zealand. By Leonard Frank Spath, D.Sc., F.G.S.

Contents.

(1) Introduction.

Dr. Trechmann, who had been favoured with identifications from Mr. S. S. Buckman, at first had the intention of dealing in the foregoing paper with some of the ammonites that he had collected in New Zealand; but, at his request, I have undertaken, in this appendix, a description of a larger series of ammonites, incorporating therewith observations on certain New Zealand specimens long since acquired by the British Museum (Natural History) and others sent recently by Prof. P. Marshall and the Geological Survey of New Zealand. The examples originally forwarded by Dr. Trechmann included five belonging to the genus *Psiloceras*, of the Lower Lias, and five ammonites from the Upper Jurassic, representing the genera *Phylloceras*, *Uhligites*, and '*Aulacosphinctes*'. In addition there were an unidentifiable fragment of probably an Upper Jurassic ammonite, from Kohai Point, and several Senonian forms, already briefly mentioned

[1] 'The Trias of New Zealand' Q. J. G. S. vol. lxxiii (1917–18) p. 215.

VII.—Synopsis of the Fossil Mollusca and Brachiopoda hitherto known or described from the Jurassic of New Zealand.

Name.	Locality.	Supposed Horizon.	Reference.	Collection.	Affinities, Occurrence elsewhere, Remarks, etc.
Cephalopoda.					
Psiloceras (Euphyllites ?), sp. nov.? indet.	Taylor's Creek, Hokonuis.	Hettangian.	Appendix, p. 288.	Trechmann.	Group of *Psiloceras calcimontanum* (Eastern Alps).
Psiloceras (Euphyllites ?), sp. indet.	Do.	Do.	" p. 289.	Do.	
Psiloceras sp. cf. *calcimontanum* (Wæhner)	Do.	Do.	" p. 289.	Do.	
Phylloceras aff. *partschi* (Hauer)	'New Zealand.'	Domerian.	" p. 290.	B.M.	Fauna of *Terebratula-aspasia* Beds (Sicily).
Rhacophyllites aff. *diopsis* (Gemmellaro)	Do.	Do.	" p. 292.	Do.	
[Rh]ysanoceras cf. *cornucopia* (Young & Bird)	Do.	Do.	" p. 293.	Do.	
Phylloceras aff. *mediterraneum*, Neumayr	Totara Point, Kawhia.	Argovian ?	" p. 294.	Trechmann.	(Universal.)
Phylloceras cf. *polyolcum* (Benecke)	Kohai Point, Kawhia.	Kimmeridgian ?	" p. 296.	Do.	*Phylloceras polyolcum* (Benecke) '*acanthicus*' zone.
Phylloceras sp.	Do.	Argovian ?	N. J. f. Min. vol. i (1911) p. 17.	Bœhm.	*Phylloceras malayanum* (in Bœhm).
Lytoceras cf. *rex* Waagen	Totara Point, Kawhia.	Kimmeridgian ?	Appendix, p. 297.	Marshall.	*Lytoceras rex* (Katrol group).
Uhligites hectori Spath	Te Puti Point, Kawhia.	Tithonian.	" p. 298.	Trechmann.	Group of *Streblites kraffti* Uhlig (Spiti Shales).
Streblites motutaranus Bœhm	Motutara Bluff, Kawhia.	Do.	N. J. f. Min. vol. i (1911) p. 17.	Bœhm.	Do. Do. *indopictus* (Spiti Shales).
Aulacosphinctoides brownei (Marshall)	Te Puti Point, Kawhia.	Do.	Appendix, p. 298.	Trechmann.	*Aulacosphinctoides* of Spiti Shales.
Aulacosphinctoides sp. indet.	Do.	Do.	" p. 299.	Do.	Do. Do.
Perisphinctes sp.	Motutara Bluff, Kawhia.	Do.	N. J. f. Min. vol. i (1911) p. 21.	Bœhm.	Do. Do.
Ammonites novoseelandicus Hauer.	Takatahi, Kawhia.	Do.		Vienna.	*Berriasella* of Alpine *privasensis* zone.
Belemnites canaliculatus aucklandicus Hauer.	Motutara; Te Puti, etc.	...	Bœhm, N. J. f. Min. vol. i (1911) p. 16.	Bœhm.	
Belemnopsis sp.	Totara Point, Kawhia.	Bathonian–Oxfordian.	This paper.	Trechmann.	Cf. *B. fleuriausus* of Great Oolite and *B. parallelus* of Fuller's [illegible]
Belemnopsis sp.	Te Ahu Ahu, Kawhia.	Do.	This paper.	Do.	Cf. *B. taliabuticus* and *B. galoi* Bœhm from the Sula Islands.
Belemnopsis sp.	Te Puti Point, Kawhia.	Kimmeridgian ?	This paper.	Do.	Cf. *B. lagoicus* Bœhm from the Sula Islands.
Belemnopsis sp.	Do.	Do.	This paper.	Do.	Do. Do.
Gasteropoda.					
Pleurotomaria sp.	Taylor's Creek, Hokonuis.	Hettangian ?	This paper.	N.Z. Surv.	Cf. group of *P. mirabilis* and *P. actinomphala*.
Pleurotomaria sp.	Totara Point, Kawhia.	Bathonian–Oxfordian.	This paper (mentioned).	Trechmann.	Shape of *P. anglica*.
Cerithinella sp.	Do.	Do.	This paper.	Do.	Near *C. bajociensis*.
Amberleya zealandica, sp. nov.	Do.	Do.	This paper.	Do.	Group of *A. capitanea* and *A. ornata*.
Naticoid sp. (small species)	Taylor's Creek, Hokonuis.	Hettangian.	This paper (mentioned).	Do.	
Lamellibranchiata.					
Parallelodon egertonianus Stoliczka	Waikato.	Upper Jurassic.	This paper.	Bartrum & Trechmann.	Occurs in the Himalayas, Arabia, and Somaliland.
Leda sp.	Flag Hill, Hokonuis.	Callovian ?	This paper.	...	Group of *L. rostralis* and *L. graphica*.
Inoceramus haasti Hochstetter	Kohai Point, Kawhia.	...	'Neu-Seeland' 1863, p. 130.	Vienna.	
Inoceramus haasti Hochstetter	Do.	Oxfordian ?	This paper.	Trechmann.	Group of *I. galoi* Bœhm from the Sula Islands.
Inoceramus cf. *galoi* Bœhm	Totara Point, Kawhia.	Bathonian–Oxfordian.	This paper.	Do.	Apparently identical with *I. galoi* Bœhm from the Sula Islands.
Pleuromya sp.	Do.	Do.	This paper.	Do.	Resemblance to forms in the Argentine Cordillera.
Aucella plicata Zittel. Zittel's specimens	Waikato.		'*Novara* Reise'—Paläontologie' 1864, p. 32.	Vienna.	
Aucella plicata Zittel. Bœhm's specimens	Kohai Point & Capt. King.	Oxfordian ?	N. J. f. Min. vol. i (1911) p. 13.	Bœhm.	
Aucella plicata Zittel. Trechmann's specimens	Kohai Point, Kawhia.	Do.	This paper.	Trechmann.	
Aucella spitiensis cf. var. *extensa* Holdhaus	Waikato.	'Upper Jurassic.'	This paper.		Group of *Aucella* [illegible] *A.* [illegible] H[illegible]
Aucella spitiensis cf. 'forma typica'	Do.	Do.	This paper.		Do. D[illegible]
Aucella (?) marshalli, sp. nov.	Roaring Bay, Nugget Point.	'Middle Jurassic.'	This paper.	Marshall.	Probably a new [illegible]
Pecten (Syncyclonema) sp.	Flag Hill, Hokonuis.	Callovian ?	This paper.	Trechmann.	Group of *P*[illegible]
Pecten (Camptonectes) cf. *lens* Sowerby	Totara Point, Kawhia.	Bathonian–Oxfordian	This paper.	Do.	Group of *P. lens*, w[illegible]
Lima aff. *gigantea* Sowerby	Puti Point & Motutara.		N. J. f. Min. vol. i (1911) p. 15.	Bœhm.	Resemblance to *L.* [illegible]
'*Pseudomonotis*' *marshalli*, sp. nov.	Flag Hill, Hokonuis.	Callovian ?	This paper.	Trechmann	Apparently a new [illegible]
Pseudomonotis cf. *echinata* Sowerby	Nugget Point to Catlins.	'Lower Oolite.'	This paper.	N.Z. Surv.	Apparently identical with *Ps.* [illegible]
Pteria cf. *contorta* Portlock	South Peak, Hokonuis.	'Rhætic'?	This paper.	Do.	Resemblance to *P.* [illegible]
Placunopsis striatula Zittel	Waikato.	Upper Jurassic.		Bartrum.	Fixed to a shell of [illegible]
Oxytoma sp.	Taylor's Creek, Hokonuis.	Hettangian.	This paper.	Trechmann.	Cf. *O. munsteri* Br[illegible]
Oxytoma sp.	Do.	Do.	This paper.	Do.	Cf. *O. cygnipes* Young & Bird ?
Oxytoma sp.	Do.	Do.	This paper.	Do.	
Oxytoma sp.	Totara Point, Kawhia.	Bathonian–Oxfordian.	This paper.	N.Z. Surv.	Cf. *Avicula costata* [illegible]
Tancredia (?) sp. (small species)	Taylor's Creek, Hokonuis.	Hettangian.	This paper (mentioned).		
Trigonia kawhiana, sp. nov.	Totara Point, Kawhia.	Bathonian–Oxfordian.	This paper.	Do.	Resembles several [illegible] Arge[illegible]
Astarte spitiensis Stoliczka	Do.	Do.	This paper.	Trechmann.	Occurs in the Spiti Shales of the Himalayas.
Astarte cf. *sowerbyana* Holdhaus	Do.	Do.	This paper.	Do.	Do. Do.
Astarte cf. *scytalis* Holdhaus	Do.	Do.	This paper.	Do.	Close resemblance [illegible] Spiti Shales.
Astarte (Opis?) morgani, sp. nov.	Do.	Do.	This paper.	Do.	Resemblance to forms in the Spiti Shales of the Himalayas.
Astarte sp. (small species)	Taylor's Creek, Hokonuis.	Hettangian.	This paper (mentioned).	Do.	
Brachiopoda.					
Discina kawhiana Bœhm	Te Puti Point, Kawhia.	Upper Jurassic.	N. J. f. Min. vol. i (1911) p. 6.	Bœhm.	
Rhynchonella sp.	Captain King, Kawhia.	...	*Ibid.* p. 7.	Do.	Cf. *Rh.* [illegible]
Rhynchonella sp.	Flag Hill, Hokonuis.	Callovian ?	This paper.	Trechmann	Cf. *Rh.* [illegible] the Callovian.
Rhynchonella sp.	Do.	Do.	This paper.	Do.	Cf. *Rh.* [illegible] K[illegible]
Rhynchonella sp. [sp. nov.	Taylor's Creek, Hokonuis.	Hettangian.	This paper.	Do.	A Rhynchonellid [illegible] Beds.
Rhynchonella (Cryptorhynchia) kawhiana, [Kitchin	Totara Point, Kawhia.	Bathonian–Oxfordian.	This paper.	Do.	Possibly a [illegible] of *Rh.* [illegible] of the Putchum
Terebratula (Kutchithyris) cf. *acutiplicata*	Do.	Do.	This paper.	Do.	Very like a form common in the Upper Putchum Beds of Kutch.
Terebratula (Heimia ?) sp.	Flag Hill, Hokonuis.	Callovian ?	This paper.	Do.	Cf. *Terebratula* [illegible] of the Upper Putchum Beds.
'*Spiriferina*' (?) sp.	Do.	Do.	This paper.	Do.	A survivor of some N.Z. Triassic Spiriferida.
Hectoria (Clavigera) cuneiformis Trechmann	Taylor's Creek, Hokonuis.	Lower Lias.	Q.J.G.S. vol. lxxiii (1917–18) p. 237.	N.Z. Surv.	A survivor of a N.Z. Triassic genus.

elsewhere [1]; further, a Jurassic *Phylloceras* and a *Lytoceras* belonging to Prof. Marshall.

The Liassic ammonites in the British Museum, described below, belong to the genera *Phylloceras*, *Rhacophyllites*, and *Lytoceras* (*Thysanoceras*). There is no detailed information available with these specimens, the matrix of which is a hard, dark-green rock, exactly like that of one of the Upper Triassic *Pinacoceras* recorded by Dr. Trechmann,[2] or of the Hettangian *Psiloceras*. These had been bestowed among Neocomian ammonites, perhaps on account of the green matrix, the *Lytoceras* fragment being labelled '*Crioceras*.'

With them was the indeterminable impression of an ammonite in an unlocalized, similarly hard, compact, dark-green rock. [Two additional examples of probably the same species as the indeterminable impression have, however, been received from the New Zealand Geological Survey since these notes were read, and show that the ammonite is not Triassic or Liassic, like the other specimens preserved in this greenish matrix, but probably entirely new, though in ornamentation and suture-line it resembles *Arcticoceras* or *Simbirskites*. Four examples of Upper Liassic *Dactylioceras* and four more Upper Jurassic Perisphinctids mentioned below, were also at the same time forwarded by the New Zealand Geological Survey, and consequently it has been possible to add important fresh evidence.]

There are also in the British Museum two Oxford Clay ammonites (*Cosmoceras duncani* J. Sowerby sp., Nos. 48751 *a* & *b*) in iron-pyrites, having the aspect of the typical Wolvercote-Summertown examples. These two specimens, labelled in Dr. Henry Woodward's handwriting 'Poverty Bay, New Zealand', were obtained from Mr. B. Isaacson in 1873; but the decomposing pyritic condition seems to be different from that which characterizes anything previously recorded from New Zealand. These two specimens, perhaps, had better not be accepted as evidence of the presence of Oxford Clay in the typical European facies, until confirmed by further collecting, especially since the locality Poverty Bay, according to the geological maps, lies in much younger rocks.

(2) Specific Descriptions.

(A) Lower Lias.

Genus Psiloceras Hyatt.

The inclusion, in this genus, of the poorly preserved forms figured in Pl. XII, figs. 1–4, is tentative, and they ought perhaps to

[1] 'Cretaceous Cephalopoda from Zululand' Ann. South Afr. Mus. vol. xii (1921) p. 299. A small ammonite in the Sir James Hector Collection in the British Museum (C 7618), 'probably from Waipara', may be a young *Parapachydiscus* or *Scaphites*, but is rather too immature for identification.

[2] 'The Trias of New Zealand' Q. J. G. S. vol. lxxiii (1917–18) p. 179 (Kaihiku Gorge).

be referred to *Euphyllites.* Whether the Annamese '*Psiloceras*' *longipontinum* (Oppel) recorded by Counillon [1] belongs to the same stock is doubtful. Few of the Alpine forms show thickening of the sigmoidal costæ at the umbilical end and extreme peripheral projection; but in the genus *Euphyllites*, which resembles the New Zealand specimens in this respect, the inner whorls are constricted.

The examples now described were first attached to *Wæhneroceras* [and since recorded as such [2]]; but the genus *Wæhneroceras* was intended to include those forms that like *W. circacostatum* and *W. extracostatum* (Wæhner) lead up to the typical *Schlotheimia*, and Wæhner's very careful researches have shown that in these ammonites, before a groove is developed,[3] the ornamentation tends to thicken on the periphery, not at the middle of the side as in early Caloceratids, or at the umbilical end as in the New Zealand forms. Fig. 1 (Pl. XII), perhaps, most resembles *Wæhneroceras* in costation, or at least forms included by Hyatt in this genus. But *Wæhneroceras megastoma*, like *Ægoceras panzneri* Wæhner,[4] rather suggests a tendency in the direction of *Pseudætomoceras* Spath, and '*Wæhneroceras*' *emmrichi* (Gümbel) and '*W.*' *guidoni* (Sowerby), also included here by Hyatt, lead to the involute Psiloceratids of the *kammerkerense* group, better separated as an independent genus **Discamphiceras**, gen. nov.[5] The falciform striation and plicate ornament of the body-chamber are so distinct that Hahn [6] was misled into uniting this group with the totally unrelated genus *Amphiceras* Gemmellaro, of the *ibex* zone. Moreover, the suture-line, illustrated in fig. 1 *c*, is phylogenetically pre-*Psiloceras*: that is, of *Euphyllites* type.

PSILOCERAS (EUPHYLLITES?) sp. nov.? indet. (Pl. XII, figs. 1 *a*–1 *c*.)

The remarkably phylloid, if slightly worn, suture-line of this specimen, labelled *Wæhneroceras* sp. by Mr. Buckman, separates the form from any of the known species of the *planorbis* to *megastoma* zones. The fragment, however, some 55 mm. in length, is too incomplete to be named. At the smaller end the cross-section is much less elevated than at the larger, and there may have been crushing of the periphery. The suture-line is of

[1] 'Sur le Gisement Liasique de Hun-Nien' Bull. Soc. Géol. France, ser. 4, vol. viii (1909) p. 528 & pl. xi, fig. 1.

[2] W. N. Benson, 'Palæozoic & Mesozoic Seas in Australasia' Trans. N.Z. Inst. vol. liv (1923) p. 42.

[3] See also A. Hyatt, 'Genesis of the Arietidæ' Smithsonian Contrib. to Knowledge, No. 673 (1889) pp. 57–58.

[4] 'Beiträge zur Kenntnis der Tieferen Zonen des Unteren Lias in den Nordöstlichen Alpen' pt. i, Beitr. Pal. Œsterr.-Ung. vol. ii (1882) p. 81 & pl. xv, fig. 1.

[5] Genotype: *Ægoceras kammerkerense* (Guembel) Wæhner, *ibid.* pt. ii, vol. iii (1884) p. 113 & pl. xxv, figs. 1–2.

[6] 'Geologie der Kammerker-Sonntagshorn Gruppe' Jahrb. K.K. Geol. Reichsanst. vol. lx (1910) p. 358 & pl. i, fig. 3 (*Amphiceras kammerkerense*).

the *Euphyllites* type: that is, intermediate between *Phylloceras* and *Psiloceras*, and the comparison with *Wæhneroceras* (for instance, the somewhat similar but more closely costate *W.? toxophorum* Wæhner sp.[1] with appreciably different suture-line) is thus open to criticism.

Locality.—Junction of Taylor's Creek with the Otapiri, Hokonui Hills.

Horizon.—Lower Lias, Hettangian; *planorbis* zone, s. l. (*megastoma* hemera).

Psiloceras (Euphyllites?), sp. indet. (Pl. XII, figs. 3, 4 *a*, & 4 *b*.)

The dimensions of the largest example (fig. 3) labelled *Wæhneroceras* sp. by Mr. Buckman, are: 39, 30, ?, 41.[2] The periphery is compressed, and the flexicostæ are thickened on the inner half of the side as in *Ægoceras calcimontanum* Wæhner. The specimen, however, is poorly preserved.

A smaller example (fig. 4 *a*) has the following dimensions: 25, 40, 31, 34. The last half-whorl belongs to the body-chamber. I succeeded in exposing the suture-line of this form, but the drawing here reproduced is somewhat restored. It is not unlike that of *Psiloceras erugatum* (Bean MS.) Phillips sp. as figured by me,[3] and agrees in general outline and phylloid saddles with the suture-lines of *Psiloceras* of the *megastoma* bed from the Pfonsjoch, in the British Museum (for instance, Nos. C 13866 & 69: *Psiloceras loxoptychum* Wæhner sp.; C 13781: *P.* sp. nov. cf. *rahana* Wæhner sp.), but is still more phylloid than those of typical species of *Wæhneroceras*.

A small and fragmentary specimen (No. 5), not figured, probably belonging to the same form, shows well the fine striation that forms the continuation of the bulging costæ of the inner half of the sides. This is exactly like the ornamentation of *Euphyllites*, but *Euphyllites struckmanni* (Neumayr)[4] has constricted inner whorls.

Locality and horizon as above.

Psiloceras sp. cf. calcimontanum (Wæhner). (Pl. XII, figs. 2 *a* & 2 *b*.)

1884. *Ægoceras calcimontanum* Wæhner, 'Beiträge zur Kenntnis der Tieferen Zonen des Unteren Lias in den Nordöstlichen Alpen' Beitr. Pal. Œsterr.-Ung. vol. iii, p. 112 & pl. xxiv, fig. 1.

Mr. Buckman compared this specimen, of dimensions: 40, 34, 33, 41, with '*Ægoceras megastoma* Wæhner, V, 7' (=*Ægoceras*

[1] *Op. cit.* pt. ii, vol. iii (1884) p. 18 & pl. xii, fig. 5.

[2] Diameter in mm.; greatest whorl-height, thickness, and umbilicus in percentages.

[3] 'The Development of *Tragophylloceras loscombi*' Q. J. G. S. vol. lxx (1914) pl. l, fig. 4.

[4] See Wæhner, *op. cit.* pt. viii (1898) p. 284 & pl. xxii, fig. 4 *a*.

anisophyllum), but there are important differences between the New Zealand example and typical specimens of Wæhner's two species from the Schreinbach in the British Museum (Nos. 23116, 117, 118). The species to which the New Zealand form is now attached shows, perhaps, more compressed whorls. It is probably transitional to the forms mentioned above that lead to *Discamphiceras*: that is, it is not of the *Wæhneroceras* stock.

The Annamese *Psiloceras longipontinum*, above mentioned, with an umbilicus of about 50 per cent. of the diameter, is more evolute, and has longer ribs. Oppel's original[1] re-examined by Neumayr, apart from being still more evolute, was described as having, for a *Psilonotus*, narrow and sharp costæ.

Of Alpine forms of *Psiloceras* from the typical locality Pfonsjoch in the Tyrol, preserved in the British Museum, a specimen close to *Psiloceras gernense* Neumayr sp. (No. C 13864), with a typically phylloid suture-line, is perhaps comparable with the example here described; but the latter, on the outer whorl, develops the peculiar *Euphyllites*-like costation of the other specimens here described.

Locality and horizon as above.

(B) Middle Lias.

Genus Phylloceras Suess.

Phylloceras aff. partschi (Stur MS.) Hauer sp. (Pl. XVIII, figs. 1 *a* & 1 *b*.)

Besides the figured example, of dimensions: 130, 56, 27, 11, there is, in the British Museum, another worn specimen, consisting of about half of an ammonite of similar size and showing the same peculiar ribbing, distinguished from that of the Argentine form figured by Burckhardt[2] by being continuous almost to the umbilicus. Similarly ribbed forms of *Phylloceras* occur, of course, at many horizons up to the Cretaceous; but there appears to be no figured example that agrees with the New Zealand specimens. The reference to the Liassic *partschi* group is suggested by their association with the *Lytoceras* and *Rhacophyllites* here described.

Hauer's[3] type-figures are characterized by very straight costation, but other authors, as, for example, Geyer,[4] included in this species forms with more sigmoidal and also more continuous costation, and Meneghini[5] drew attention to the variations in ornamentation that occur in this group. The form figured by Reynès[6]

[1] Pal. Mitteil. 1862, p. 129 & pl. xli, fig. 1.

[2] 'Beiträge zur Kenntnis der Jura- & Kreideformation der Cordillere' Palæontographica, vol. l (1903) p. 6 & pl. i, fig. 1.

[3] 'Beiträge zur Kenntnis der Heterophyllen der Œsterreichischen Alpen' Sitz. Ber. K. Akad. Wissensch. Wien, vol. xii (1854) p. 881 & pl. iv, figs. 1–8.

[4] 'Mittelliasische Cephalopoden des Schafberges, &c.' Abhandl. K.K. Geol. Reichsanst. vol. xv (1893) p. 42 & pl. v: for instance, fig. 8.

[5] 'Fossil. d. Medolo' in Stoppani: 'Pal. Lombarde' Append. (1881) p. 27.

[6] 'Monographie des Ammonites' 1879, Atlas, pl. xxxiv, figs. 30–32.

with continuous, though less sigmoidal costation, differs in thickness and width of the umbilicus; but the New Zealand example being slightly crushed obliquely, the opposite side does not show the flexiradiate character, conspicuous in fig. 1 *a* of Pl. XVIII.

Phylloceras anonymum Haas [1] has similarly continuous costation which, however, is straight, as in the typical *Ph. partschi*. Dumortier's [2] *Ammonites atlas* is considerably inflated, and the gigantic *Phylloceras seroplicatum* (Hauer) [3] does not acquire its coarse pleating until a fairly late stage.

The fragmentary example shows the suture-line more clearly than does the figured specimen. This suture-line agrees with that of *Phylloceras tenuistriatum* (Meneghini) as figured by Fucini.[4] Specimens of this form, however, from Campiglia (British Museum, *ex* Dr. F. Castelli Coll., agreeing with Reynès's [5] fig. 16) have different ornamentation.

Locality.—Unrecorded.

Horizon.—Middle Lias (Domerian).

Genus RHACOPHYLLITES Zittel emend.

Pompeckj [6] suggested that the genus *Rhacophyllites* might be restricted to the ornamented forms, and I [7] proposed to take as typical the group of *Rh. transylvanicus–diopsis*.[8] Apart from these, many evolute Phylloceratids with diphyllic suture-lines, belonging to various groups from the Triassic *Discophyllites* upwards, have been included in '*Rhacophyllites*', on account of their narrower whorls, with a correspondingly smaller number of auxiliary elements of their suture-lines. Of these, the Hettangian group of '*Rhacophyllites*' *stella* (Sowerby) could be separated with a new name: **Paradasyceras**, gen. nov., the genotype to be *Phylloceras uermösense* (Herbich) Wæhner.[9] The constricted inner whorls of *P. stella* as figured by me [10] and the 'rhacophyllitic' suture-line are characteristic; but attention has already been

[1] 'Die Fauna des Mittleren Lias von Ballino, &c.' Beitr. Pal. Geol. Œsterr.-Ung. vol. xxvi (1913) p. 7 & pl. i, figs. 1–5.

[2] 'Etudes Paléontologiques sur les Dépôts Jurassiques du Bassin du Rhône' vol. iv (1874) p. 106 & pl. xxx, figs. 4–6.

[3] *Op. cit.* 1854, p. 862 & pl. i, fig. 1.

[4] 'Cefalopodi Liassici del Monte di Cetona' pt. i, Pal. Ital. vol. vii (1901) p. 33, text-fig. 16.

[5] *Op. cit.* 1879, pl. xliv; *non* Geyer, *op. cit.* 1893, pl. vi, figs. 1 & 2.

[6] 'Beiträge zu einer Revision der Ammoniten des Schwäbischen Jura' pt. i (1893) p. 39.

[7] 'The Development of *Tragophylloceras loscombi*' Q. J. G. S. vol. lxx (1914) p. 355.

[8] Lectotype: *Phylloceras diopsis* Gemmellaro, 'Sui Fossili degli Strati a *Terebratula aspasia*' pt. i, Soc. Sci. Nat. & Econ. Palermo (1884) p. 6 & pl. ii, figs. 6–8.

[9] Wæhner, pt. viii (1898) p. 173 & pl. xxv, fig. 1 only (B.M. C 23140 from Schreinbach, Wolfgangsee, Austria, *ex* Panzner Coll.).

[10] Q. J. G. S. vol. lxx (1914) pl. l, figs. 1–3.

drawn to the difficulty of distinguishing these *Paradasyceras* from their contemporaries *Phylloceras* and *Geyeroceras*.[1]

I now consider it probable that from this persistent radical stock of evolute Phylloceratids, including, in the Middle and Upper Jurassic, the genus *Sowerbyceras*, have successively originated the 'cryptogenous' families of trachyostracous ammonites, some by way of transitional types of the *Lissoceras*, *Haploceras*, and *Desmoceras* pattern, erroneously united into 'families.' The genus now defined as *Rhacophyllites* (but not its specialized adults) thus probably gave rise to *Tragophylloceras*,[2] and the genus *Amphiceras* and the family Amaltheidæ may have sprung from the same radical Phylloceratid stock.

The modified offshoots with robust ornamentation generally show simplification of the suture-lines, changes that are probably effected in the early stages and correlated with adaptation to a mode of life different from that of the leiostracous parent stock which never left the warmer seas of the Tethys.

Other modified Phylloceratids, such as the 'Purbeckian' *Phylloceras strigile* (Blanford), the ornamentation of which somewhat resembles that of the contemporaneous, dominant ammonite family Berriasellidæ, leave no progeny, and remind one of the curious simultaneous appearance of the umbilical processes in the Lower Triassic *Otoceras* and its contemporary Nautili, perhaps examples of mimicry.

RHACOPHYLLITES aff. DIOPSIS (Gemmellaro). (Pl. XVIII, figs. 2 *a*–2 *c*.)

1884. *Phylloceras diopsis* Gemmellaro, 'Sui Fossili dei Strati a *Terebratula aspasia*, &c.' pt. i, Soc. Sci. Nat. & Econ. Palermo, p. 6 & pl. ii, figs. 6–8.

The specimen here described consists of the body-chamber portion of about half a whorl, of an ammonite some 70 mm. in diameter, but showing signs of crushing. The umbilicus is nearly 25 per cent. of the diameter, or about the same width as in the Sicilian type. The resemblance of the ornamentation to that of certain *Tragophylloceras*, notably *T. ibex-heterophyllum* (Quenstedt),[3] is partly due to the crushing of the whorl and its periphery. There is a likeness to a *Rhacophyllites* of the *gigas* type from the Toarcian (?) of the Kammerker Alpe, Tyrol (Klipstein Coll. B.M. No. C 13856), but less resemblance to the Lower Liassic Campiglia forms (*Rhacophyllites nardii* Meneghini sp.) in the British Museum collections.

The beginning of the body-chamber shows portions of the saddles of the last suture-line, but not the lobes. The external, first and second lateral saddles are very distinctly diphyllic, the

[1] L. F. Spath, Q. J. G. S. vol. lxx (1914) pp. 354–55.

[2] 'Notes on Ammonites' Geol. Mag. vol. lvi (1919) p. 29, footnote 4 & p. 221. The 'recapitulation theory' has since been practically abandoned.

[3] 'Ammoniten des Schwäbischen Jura' 1885, pl. xxxvii, fig. 14 & p. 294 = *Phylloceras* sp. in Pompeckj, *op. cit.* 1893, pt. i, pp. 13 & 18.

auxiliary saddle unsymmetrically so, as in fig. 8 of Gemmellaro's pl. ii. Apparently there is only one more auxiliary saddle, whereas *Rhacophyllites gigas* Fucini,[1] *Rh. transylvanicus* (Hauer)[2] and the varieties of that species in Fucini[3] which agree with the New Zealand example in the small umbilicus, have more numerous auxiliary elements.

There are two or three (indistinct) constrictions and an irregularity in the costation, due to an injury, which helps to accentuate the *ibex*-like appearance of the specimen, reminiscent of the two *Tragophylloceras* of the *wechsleri* group, figured by Wright,[4] or of *Amphiceras mariani* Gemmellaro.[5]

'*Rhacoceras*' *numismale* (Quenstedt) Fucini,[6] which has a flattened aspect, similar to that of the specimen here described, is fairly involute, but badly preserved, and may only be a narrowly umbilicated *Rhacophyllites*, not a *Tragophylloceras*.

The example of *Rhacophyllites* cf. *gigas* Fucini, recorded by Diener[7] from the Himalayas, represents a more evolute and less coarsely costate form than the New Zealand specimen.

An example of *Rh. libertus* (Gemmellaro), from the Upper Lias of Foci di Cantiano in the Apennines (B.M. No. C 8410), labelled *Ammonites (Rhacophyllites) diopsis* Gemmellaro, by Prof. Zittel himself, like the Sicilian type[8] or like another example from the Valley of Kelat, Baluchistan (Geol. Soc. Coll.), is more evolute and has less coarse costation than the New Zealand form.

Locality and horizon as above.

Genus Thysanoceras Hyatt, emend. S. Buckman.

Thysanoceras cf. cornucopia (Young & Bird). (Pl. XVIII, figs. 3 *a* & 3 *b*.)

A fragment of a Lytoceratid, in whorl-shape and ornamentation, closely resembles Young & Bird's[9] Yorkshire species, to which a

[1] *Op. cit.* 1901, p. 56 & pl. ix, figs. 2, 4.

[2] In Herbich, 'Das Szeklerland' Mitteil. Jahrb. K. Ungar. Geol. Anst. vol. v (1878) p. 114 & pl. xx j, fig. 1.

[3] *Op. cit.* 1901, pp. 53, &c. & pl. viii, figs. 1–7.

[4] 'Monograph of the Lias Ammonites' Pal. Soc. pt. iii (1880) pl. xxxix, figs. 1–3 (*Ægoceras loscombi* Sowerby). These specimens are not in the Wright Collection in the British Museum; but fig. 3, to judge by a Radstock example, may be a badly drawn *Tragophylloceras wechsleri*, whereas figs. 1 & 2 represent a form with broader periphery sufficiently distinct to receive a new name (**T. radstockense** nov.).

[5] 'Sui Fossili dei Strati a *Terebratula aspasia*' pt. i, Soc. Sci. Nat. & Econ. Palermo (1884) p. 33, & pl. i, figs. 13–14 (typus).

[6] *Op. cit.* (1901) p. 15 & pl. ii, fig. 4.

[7] 'Upper Triassic & Liassic Faunæ of the Exot. Blocks of Malla Johar, &c.' Mem. Geol. Surv. India, Pal. Indica, ser. 15, vol. i, pt. 1, p. 76 & pl. xi, fig. 1.

[8] *Op. cit.* (1884) p. 4 & pl. ii, figs. 1–2.

[9] 'Geol. & Miner. Survey of the Yorkshire Coast' 1822, pl. xii, fig. 6, as interpreted in S. S. Buckman, 'On Lytoceratidæ' Q. J. G. S. vol. lxi (1905) p. 149.

New Caledonian specimen, recorded by Piroutet,[1] had been compared. *Lytoceras siemensi* (Denckmann),[2] which may be identical with the Whitby form, has a similar whorl-section; but, since the New Zealand example, like the *Phylloceras* described above, has been crushed, at least at the smaller end, perhaps not much importance can be attached to the compressed whorl-shape. Moreover, the Lower Liassic *Fimbrilytoceras*, for instance *F. tuba* (De Stefani),[3] and the Middle Liassic *Lytoceras* sensu stricto, for instance *L. post-fimbriatum* Prinz,[4] may show compressed whorls similar to the Toarcian *Thysanoceras* of the *cornucopia* type. The reticulate ornament is shown also in the true *Fimbrilytoceras fimbriatum* (J. Sowerby),[5] although here the ribs are not inclined backwards as in the Toarcian form.

Lytoceras francisci (Oppel)[6]=*Ammonites fimbriatus* Hauer[7] ex parte, differs from the example here described in having costation with an anteriorly convex sinus on the periphery; but there is no resemblance to *Lytoceras cereris* (Meneghini) Bonarelli,[8] with which form Rosenberg[9] included Hauer's example. *Fimbrilytoceras fimbriatoides* (Gemmellaro)[10] is distinguished from the form here described by its circular cross-section.

The details of the suture-line, with its extremely wide first lateral and high external lobes, are not preserved; but, although the specimen is slightly worn, probably there were no plain 'flares' as in the true *Lytoceras*.

Locality and horizon as above.

(C) Upper Jurassic.

Genus PHYLLOCERAS Suess.

PHYLLOCERAS aff. MEDITERRANEUM (Neumayr) auct. (Pl. XIV, fig. 1.)

The large example illustrated in Pl. XIV, fig. 1 (reduced to about

[1] 'Note Préliminaire sur la Géologie d'une Partie de la Nouvelle Calédonie' Bull. Soc. Géol. France, ser. 4, vol. iii (1903) p. 155.

[2] 'Fauna des Oberen Lias von Dœrnten' Abhandl. K. Preuss. Geol. Landes-Anst. vol. viii (1887) p. 156 & pl. i, fig. 8.

[3] 'Lias Inferiore ad Arieti, &c.' Atti Soc. Tosc. Sci. Nat. Mem. vol. viii (1887) p. 62 & pl. i, figs. 17, 18.

[4] 'Fauna der Ælteren Jurabildungen im Nordöstlichen Bakony' Mitteil. Jahrb. K. Ungar. Geol. Anst. vol. xv (1904) pp. 52–53 (=*Ammonites fimbriatus* A. d'Orbigny, pl. xcviii, *non* Sowerby).

[5] See S. S. Buckman, 'Yorkshire Type-Ammonites' vol. ii (1919) pl. cxxx *c*, fig. 2.

[6] 'Die Tithonische Etage' Zeitschr. Deutsch. Geol. Gesellsch. vol. xvii (1865) p. 551; non *Lytoceras francisci* Vacek, 'Oolithe von Cap San Vigilio' Abhandl. K.K. Geol. Reichsanst. vol. xii (1886) p. 4 (60) & pl. ii, figs. 1–2.

[7] 'Cephalopoden aus dem Lias der Nordöstlichen Alpen' 1866, p. 62 & pl. xxii, figs. 1–2 only.

[8] 'Le Ammoniti del Rosso Ammonitico, &c.' Bull. Soc. Malac. Ital. vol. xix (1894) p. 216 (=*Ammonites cereris* Meneghini, in Stoppani, 'Pal. Lombarde' [4] 1867, pl. xxi, fig. 3 only).

[9] 'Liasische Cephalopoden-Fauna der Kratz-Alpe im Hagengebirge' Beitr. Pal. Geol. Œsterr.-Ung. vol. xxii (1909) p. 241.

[10] *Op. cit.* (1884) p. 13 & pl. iii, figs. 20–23.

a quarter of the natural size) had its body-chamber accidentally displaced; but its normal diameter probably was not less than 300 mm. In the figure a break is shown at *b*, and the line of displacement at *d*. There are seven constrictions and about eight intervening ribs on the peripheral portion of the whorl, as in *Phylloceras passati* Bœhm,[1] with which species the example had been identified by Dr. Trechmann. This costation does not seem to be yet developed at a size corresponding with that of the Wai Galo form, appearing in the specimen here described at a diameter of about 250 mm. Furthermore, the constrictions have a different course in the New Zealand form. The outer half, in side-view, forms a very pronounced semicircular curve, and there is a very distinct sinus forward on the periphery, reminiscent of *Sowerbyceras* or *Schlueteria*. This sinus is more prominent than that shown in Neumayr's type of *Phylloceras mediterraneum*,[2] from the Alpine *macrocephalus* beds (with a similar number of constrictions but less lateral angularity), or by Haug's[3] Bajocian example, with nine constrictions.

Phylloceras mediterraneum, race *indica* Lemoine[4] does not show this type of constriction, nor do the Argovian examples recorded by me[5] from Tunisia. These have only five constrictions; but it is to be noted that, at a diameter corresponding with that of the Trept specimens,[6] the form here described also has only five constrictions, although in this case the forward sinus on the periphery is even more conspicuous. In order to obtain these inner whorls, a worn example from the same locality as the large figured specimen was broken up, revealing the distinctness of the species. Whether *Phylloceras kawhiæ* Marshall[7] or *Phylloceras* sp. in Bœhm[8] are identical with the form here described it is impossible to state.

The suture-line is well-preserved, especially on the smaller specimen, and agrees in general outline with that of *Phylloceras mediterraneum* as figured by Canavari.[9] Of the four larger leaflets

[1] 'Die Südküsten der Sula-Inseln Taliabu & Mangoli' Palæontographica, Suppl. iv, pt. 3: 'Oxfordien des Wai Galo' (1907) p. 82 & pls. xv, xvi, xvii.

[2] 'Jurastudien: III. Phylloceraten des Dogger & Malm' Jahrb. K.K. Geol. Reichsanst. vol. xxi (1871) p. 340 & pl. xvii, figs. 2–5.

[3] 'Note sur le Péristome du *Phylloceras mediterraneum*' Bull. Soc. Géol. France, ser. 3, vol. xviii (1890) p. 328 & pl. iv.

[4] 'Paléontologie de Madagascar: pt. 8 – Ammonites d'Analalava' Ann. Pal. vol. v (1910) p. 3 & pl. i, fig. 1.

[5] 'Jurassic Ammonites from Jebel Zaghuan' Q. J. G. S. vol. lxix (1913) p. 561.

[6] A. de Riaz, 'Description des Ammonites des Couches à *Peltoceras transversarium* de Trept (Isère)' 1898, p. 40 & pl. xvi, figs. 9–10.

[7] 'Some New Zealand Fossil Cephalopods' Trans. N.Z. Inst. vol. xli (1908) p. 144 & pl. xiv *a*, fig. 2673, right-hand fig.

[8] 'Grenzschichten zwischen Jura & Kreide von Kawhia' Neues Jahrb. vol. i (1911) p. 17.

[9] 'La Fauna degli Strati con *Aspidoceras acanthicum* di Monte Serra' Pal Ital. vol. ii (1896) text-fig. 6 on p. 39.

of the external saddle, however, the outer (siphonal) pair are at a higher level than the inner pair, and the inner of the two leaflets of the first lateral lobe is higher than the outer in the New Zealand form, points in which there is agreement with *Phylloceras passati*.

Since the species now described is probably new, it is of no use for dating the beds at Totara Point. The resemblance of the ribbing to that of the Argovian *Ph. passati* may be of no significance; and, moreover, it is found again in the Callovian *Ph. mamapiricum* Bœhm.[1] Bœhm considered it not impossible that this species, as well as *Ph. passati*, may yet prove identical with *Ph. mediterraneum*; and it is noteworthy that the peripheral sinus is more pronounced in the early types. On the other hand, the mode of preservation of the specimens now discussed is exactly the same as that of the *Phylloceras* next described, from Kohai Point.

Locality.—Totara Point. With the smaller specimen, marked 'Totara Point' in ink, is, however, a label: 'Te Ahu Ahu (by the Old Mission Station) Belemnite-Beds.' A *Phylloceras* from the latter locality, belonging to Prof. Marshall, may belong to the same species.

Horizon.—Jurassic (Middle or Upper?).

PHYLLOCERAS cf. POLYOLCUM (Benecke).

1866. 'Trias & Jura in den Süd-Alpen' Pal. Beiträge, vol. i, p. 182 & pl. vii.

An example of a *Phylloceras*, measuring 180 mm. in diameter and having an umbilicus of about 10 per cent., shows eleven angular constrictions that pass straight across the periphery: that is, there is no ventral sinus as in the form just described, with which, however, it agrees in mode of preservation. There is also no ribbing on the periphery, but at a corresponding diameter *Phylloceras* aff. *mediterraneum* is equally unornamented. Like the latter, the form now described clearly belongs to the group of *Phylloceras ultramontanum* (Zittel), and differs from Benecke's type merely in not acquiring its eleven constrictions until a larger diameter. *Phylloceras tauricum* (Retowski) = *Ph. mediterraneum*, var. *tauricum*,[2] with only seven to eight constrictions at a smaller diameter, may thus be as close to the New Zealand form as Benecke's species; but Neumayr[3] had pointed out that his numerous examples of *Ph. polyolcum* from the *acanthicus* zone had only nine constrictions up to a diameter of 100 mm., and seven to eight at a still earlier stage.

According to the same author, the suture-line of *Ph. polyolcum* is slightly more slender than that of *Ph. mediterraneum*; but in

[1] 'Unteres Callovien & Coronatenschichten, &c.' Nova Guinea: Résult. Exp. Sci. Néerl. 1903, vol. vi, Geol. i, Leiden (1912) p. 7 & pl. i, fig. 3, pl. ii, figs. 1–2, text-fig. 1.

[2] 'Die Tithonischen Ablagerungen von Theodosia' Bull. Soc. Imp. Nat. Moscou (1893) nos. 2 & 3, p. 231 & pl. ix, fig. 5.

[3] Jahrb. K.K. Geol. Reichsanst. vol. xxi (1871) pp. 341–42.

the specimen here described, owing to the somewhat imperfect state of preservation, the differences are not appreciable. In both the New Zealand species the terminal leaflets of the saddles are more elongated than those depicted in Neumayr's figs. 1 & 6 of pl. xvii.

Phylloceras insulindæ Bœhm [1] has less numerous and less angular constrictions, and these are still straighter in the group of *Ph. calypso* (A. d'Orbigny), *Ph. berriasense* (Pictet), and *Ph. silesiacum* Zittel.

P. Choffat [2] pointed out that *Ph. polyolcum* had no greater stratigraphical importance than *Ph. mediterraneum*, and attention has already been drawn [3] to the unusually extensive vertical range of some of these species-groups of *Phylloceras*.

Locality.—Kohai Point.

Horizon.—Upper Jurassic (? *gigas* zone).

LYTOCERAS cf. REX Waagen.

1873. 'Jurassic Fauna of Kutch: I—Cephalopoda' Mem. Geol. Surv. India, Pal. Indica, p. 36 & pl. viii, fig. 1.

A specimen of a *Lytoceras* of the group of *L. liebigi* (Oppel), belonging to Prof. P. Marshall, about 170 mm. in diameter, but somewhat distorted, on the earlier volutions shows fairly strong lineation of the type of that of the inner whorls of *L. rex*, but has close, alternately plain and fimbriate, costæ on the outer whorl. At a whorl-height of 73 mm. the thickness is about 59 mm., and the section thus is oval, compressed, with a very slight dorsal indentation, not quite identical with that given by Waagen in his fig. 1 *b*. The suture-line is perhaps just a little less complex than that of *L. adeloides* as figured by Waagen (pl. viii, fig. 2), but of the same type.

The example now described is completely septate, and does not show the distant fimbriæ of the outer whorl of Waagen's gigantic specimen, also the stage with close fimbriæ, preceding the final stage, is very short in the Indian form; whereas, according to Waagen, up to a diameter of 300 mm., the whorls of *L. rex* are 'covered with fine, closely arranged, undulated ribs, all of equal strength.' The specimen here described, consequently, cannot be definitely identified with Waagen's species.

The numerous specimens of *Lytoceras* in the British Museum from Mombasa, East Africa, whence Dacqué [4] recorded a *Lytoceras* cf. *rex*, belong to more finely lineate species.

Locality.—Totara Point, Kawhia Harbour.

Horizon.—Upper Jurassic.

[1] Palæontographica, Suppl. iv, pt. 3 (1907) p. 83 & pl. xvii, fig. 2.

[2] 'Faune Jurassique du Portugal: I—Ammonites du Lusitanien' Comm. Trab. Geol. Portugal, 1893, p. 12.

[3] 'Jurassic Ammonites from East Africa, &c.' Geol. Mag. vol. lvii (1920) p. 320.

[4] 'Dogger & Malm aus Ostafrika' Beitr. Pal. Geol. Œsterr.-Ung. vol. xxxiii (1910) p. 9.

Genus Uhligites Kilian.

Uhligites hectori Spath. (Pl. XVII, fig. 1.)

1886. (?) *Ammonites* (Kawhia) Hector, 'Outline of the Geology of New Zealand' Ind. & Colon. Exhib. London, New Zealand Court, Catal. & Guide to Geol. Exhibits, p. 68, text-fig. 33, 2.

1923. *Uhligites hectori* Spath, 'Blake Collection of Ammonites from Kachh (India)' Mem. Geol. Surv. India, Pal. Indica.

This form is represented by an example measuring 145 mm. in diameter, with an umbilicus of 12 per cent. and a whorl-thickness of 21 per cent. of the diameter. The terminal portion of the outer whorl belongs to the body-chamber. Whether Dr. Trechmann's example (labelled *Streblites*) is identical with Hector's type cannot be decided without examination of the original. The latter seems to have a smaller umbilicus, but the type of ornamentation is well, if somewhat diagrammatically, represented in Hector's figure.

Bœhm's '*Streblites*' *motutaranus* [1] has strongly marked primary ribs on the inner half of the sides, reminiscent of *Streblites pictus* (Quenstedt), and the *Uhligites* suture-line with a peculiarly undercut external saddle. It shows slightly prorsiradiate costation, but is considerably smaller than the specimen here discussed.

Uhligites hectori probably belongs to the group of *U. kraffti* (Uhlig & Suess) [2] and *U. crassicostatus* (Uhlig),[3] well represented in the Spiti Shales. *Uhligites nouhuysi* (Bœhm) [4] is a smoother though similar type, and more involute forms occur also in the Kimmeridgian of Mexico: for instance, *Streblites uhligi* and *Str. mexicanopictus* Burckhardt.[5]

Locality.—Te Puti Point, Kawhia, loose on shore.

Horizon.—Tithonian (?).

Genus Aulacosphinctoides Spath.[6]

Aulacosphinctoides brownei (Marshall). (Pl. XVII, figs. 2*a* & 2*b*.)

1909. *Ægoceras brownei* Marshall, 'Some New Zealand Fossil Cephalopoda' Trans. N.Z. Inst. vol. xli (1908) p. 144 & pl. xvi A, fig. 4.

1911. *Perisphinctes brownei* (Marshall) Bœhm, 'Grenzschichten zwischen Jura & Kreide' *op. cit.* p. 19 & pl. i, fig. 2, also text-fig. 2.

1923. *Aulacosphinctoides brownei* (Marshall) Spath, 'Blake Collection of Ammonites from Kachh (India)' Pal. Indica.

The sectional outline depicted on Pl. XVII, fig. 2*b* was taken from a whorl-fragment that may belong to the same species as

[1] *Op. cit.* ('Grenzschichten, &c.' 1911) p. 17 & pl. ii, figs. 5 *a*, *b*.

[2] In Uhlig, 'Fauna of the Spiti Shales' Fasc. 1, Mem. Geol. Surv. India, Pal. Indica, vol. iv, Himalayan Fossils, ser. 15 (1903) p. 44, & *e. g.* pl. iv, figs. 1 *a d*.

[3] *Ibid.* fasc. 2 (1910) pl. lxxviii, fig. 2; fasc. 3 (1910) p. 391.

[4] 'Beiträge zur Geologie von Niederländisch-Indien: I—Grenzschichten zwischen Jura & Kreide' Palæontographica, Suppl. iv (1911) p. 29 & pl. ii, figs. 7–8.

[5] 'Faune Jurassique & Crétacée de San Pedro del Gallo' Bol. Inst. Geol. Mexico, No. 29 (1912) pp. 52–60 & pls. xi, xiv.

[6] 'Blake Collection of Ammonites from Kachh (India)' Mem. Geol. Surv. India, Pal. Indica, 1923.

the complete ammonite illustrated in fig. 2*a*, or to a closely similar form. The large example has a diameter of 81 mm. and a whorl-thickness of close on 35 per cent. of the diameter. There are about four constrictions per whorl. The final constriction probably formed the mouth-border, and is three-quarters of a whorl away from the last septum. The suture-line is poorly preserved, but comparatively simple, as figured by Bœhm.

Mr. Buckman labelled this example '*Perisphinctes* cf. *pagri* Waagen'. A specimen of this form in the Blake Collection (B.M. No. 543), from the Argovian Kantcote Sandstone, shows similarity to the New Zealand species, and *Perisphinctes sub-evolutus* Waagen (for instance, No. 539), from the Dhosa Oolite, also seems to be close. In these two early species, however, the inclination of the secondary ribs and the constrictions are different. *Perisphinctes burui* Bœhm [1] probably belongs to this Argovian group of *Perisphinctes*, and is thus not related to the somewhat similar New Zealand species of *Aulacosphinctoides*.

On the other hand, *Aulacosphinctoides hundesianus* (Uhlig) and *A. chidamensis* (Uhlig), if we may judge by examples in the British Museum (31107 & C 7676*a*), are closer to the present species, and one example of the same group of *Aulacosphinctoides* (33539) from the Spiti Shales might almost be identified with *A. brownei*.

A. **uhligi**, nom. nov. = *Aulacosphinctes torquatus* Uhlig *non* Sowerby [2] (B.M. No. C 5034) is slightly less densely costate; *A. incertus* (Uhlig) (B.M. C 7676*b*) and *A. serpentinus* (Uhlig) (36933) are less closely comparable.

A. **marshalli**, nom. nov. = *Perisphinctes* sp. in Bœhm [3] has slightly different costation, as I judge from an example lately sent by the Geological Survey of New Zealand.

A. sisyphi (Hector) [4] may represent a very large example of the group to which *A. brownei* and *A. marshalli* belong.

Locality.—Te Puti Point, Kawhia.

Horizon.—Tithonian (?).

AULACOSPHINCTOIDES sp. indet. (Pl. XVII, figs. 3*a* & 3*b*.)

This specimen consists of portions of two whorls, showing somewhat corroded suture-lines. Height and thickness of the outer volution amount to 28 mm., and there is an indistinct constriction on this whorl.

Mr. Buckman labelled this example '*Perisphinctes* cf. *uni-comptus* Choffat, xviii, 3,' and there is, indeed, great resemblance to the form figured by Choffat [5] and referred to Fontannes's

[1] 'Geologische Mitteilungen aus dem Indo-Australischen Archipel: VI c—Jura von Rotti, Timor, Babar & Buru' Neues Jahrb. Beilage-Band xxv (1908) p. 334 & pl. xiii, fig. 2.

[2] *Op. cit.* (1910) p. 368 & pl. lxxi, figs. 1*a*–1*d*.

[3] *Op. cit.* (1911) p. 19 & pl. i, fig. 3, text-figs. 3*a*–3*b*.

[4] *Op. cit.* (1886) p. 68 & text-fig. 33, *l*.

[5] 'Faune Jurassique du Portugal: Céphalopodes, I—Ammonites du Lusitanien' Comm. Trab. Geol. Portugal (1893) p. 46 & pl. xviii, figs. 3–5.

species, also to the *Perisphinctes* sp. (*stenocycli*) of the same author.[1] The lateral lobe, however, is deeper and wider in the New Zealand form, and the rib-curve is different. Despite the similarity of the fragment here described to European Kimmeridgian Ataxioceratids, its affinities, as of *A. brownei*, are probably with the Tithonian Perisphinctids of the Spiti Shales and their equivalents in the Malay Archipelago and New Guinea. *Aulacosphinctoides chidamensis* and *A. sparsicosta* (Uhlig)[2] are, perhaps, closest among the Spiti forms. They differ in whorl-section, and the latter also in its shorter lateral lobe. The genotype of *Aulacosphinctoides*, *A. infundibulus* (Uhlig), with regularly bifurcating ribs on the outer whorl, like the fragmentary specimen referred above to *A. brownei*, shows less resemblance to the example here described than do some forms of *Virgatosphinctes*.

Perisphinctes (Procerites) matsushimai Yokoyama,[3] on the outer whorl, shows ornamentation similar to that of the fragment now described, but, like the other Japanese forms of *Perisphinctes*, figured by the same author, is not identifiable from the figure. *Perisphinctes durangensis* Burckhardt,[4] with which the Japanese species has been compared, differs from the fragment here described in being less involute, and in having quite a different type of costation.

Apart from the trifurcation of some of the ribs on the outer whorl-portion of our example, there is considerable resemblance to some Kachh species of the group of *Perisphinctes bleicheri* Waagen *non* P. de Loriol, *P. eudichotomus* Waagen *non* Zittel, and *P. occultefurcatus* Waagen, all from the Umia Beds (see, for instance, B.M. 499, 486, Blake Coll.), but believed by me[5] to belong to the Kimmeridgian *Torquatisphinctes*, not the Tithonian *Aulacosphinctoides*. Unless the outer whorls are preserved, however, even generic distinction is extremely difficult.

Locality.—Te Puti Point, Kawhia Harbour.

Horizon.—Tithonian (?).

(3) Conclusions.

The Lower Hettangian age of the forms here recorded as *Psiloceras* (*Euphyllites?*) sp. nov. ind., *Ps.* (*Eu.*) sp. indet., and *Psiloceras* sp. cf. *calcimontanum* (Wæhner) is undoubted, and they suggest deposits probably belonging to the *megastoma* subzone: that is, the upper part of the *planorbis* zone in the wider sense.

The three species *Phylloceras* aff. *partschi* (Stur MS.) Hauer sp., *Rhacophyllites* aff. *diopsis* (Gemmellaro), and *Thysanoceras*

[1] *Ibid.* p. 51 & pl. xix, fig. 3.

[2] *Op. cit.* (1910) pl. lxxiv, figs. 1 & 2.

[3] 'Jurassic Ammonites from Echizen & Nagato' Journ. Coll. Sci. Imper. Univ. Tokyo, vol. xix, Art. 20 (1904) p. 3 & pl. i, fig. 1.

[4] 'Faune Jurassique & Crétacée de San Pedro del Gallo' Bol. Inst. Geol. Mexico, No. 29 (1912) p. 16 & pl. iii, fig. 1.

[5] L. F. Spath, *op. cit.* Pal. Indica, 1923.

cf. *cornucopia* (Young & Bird) indicate Liassic deposits of an age younger than the Sinemurian; but their exact horizon within the Lias cannot easily be determined. It is also possible, of course, that they do not all three come from the same horizon. On the one hand, the *Lytoceras* fragment resembles the Toarcian *Lytoceras (Thysanoceras) cornucopia*, previously recorded from New Caledonia, more than it does Middle and Lower Liassic species. On the other hand, the fauna of the *Terebratula-aspasia* Beds of Sicily, which includes a majority of forms of the *ibex* zone—notably most of the *Tropidoceras* found at Charmouth [1]—contains a similar assemblage of *Phylloceras*, *Rhacophyllites*, and *Lytoceras*, as does a Domerian-Toarcian fauna from Baluchistan in the British Museum (Geol. Soc. Coll.).[2] The reference of the three New Zealand forms to the Middle Lias is thus more or less provisional; but their typically Mediterranean aspect makes a direct marine connexion of the New Zealand Sea by way of New Caledonia, Rotti, and Annam with the Himalayan extension of the Tethys appear very probable.[3]

[It may here be mentioned that four specimens of Upper Lias *Dactylioceras* have since been received from the Geological Survey of New Zealand. These are: *Dactylioceras* cf. *anguinum* (Reinecke),[4] *D.* aff. *commune* (Sowerby), and *D.* spp. juv., showing a striking resemblance to forms described by Bœhm [5] as *Perisphinctes timorensis*. They are from north of Ururoa Point, outside Kawhia Harbour, but are preserved in a matrix different from that of the three examples referred above to the Middle Lias. Whether the latter are Domerian or not, the *Dactylioceras*, resembling forms found in Japan and Rotti, undoubtedly indicate the presence of the Toarcian.]

There is no ammonite definitely referable to the Middle Jurassic, for *Phylloceras* aff. *mediterraneum* Neumayr may well be of Upper Jurassic age. *Phylloceras* cf. *polyolcum* (Benecke) and *Lytoceras* cf. *rex* Waagen also cannot be accurately dated, though they are compared with forms from the *acanthicus* zone and Katrol Beds, suggesting a Kimmeridgian age. It has already

[1] See L. F. Spath, 'On a New Ammonite Genus (*Dayiceras*) from the Lias of Charmouth' Geol. Mag. vol. lvii (1920) p. 543; also, 'Correlation of the *Ibex* & *Jamesoni* Zones of the Lower Lias' *ibid.* vol. lx (1923) p. 8.

[2] L. F. Spath, 'Cretaceous Cephalopoda from Zululand' Ann. S. A. Mus. vol. xii (1921) p. 272; also H. L. Hawkins, 'Morphological Studies on the Echinoidea, &c.: pt. xii—*Pseudopygaster*, &c.' Geol. Mag. vol. lix (1922) pp. 213–14.

[3] See E. Haug, 'Traité de Géologie' vol. ii, fasc. 2 (1907) map on p. 1113. Also E. Dacqué, 'Der Jura in der Umgebung des Lemurischen Kontinents' Geol. Rundschau, vol. i (1910) p. 164.

[4] This form is not identical with that which characterizes the lowest horizon of the *falcifer* zone; see L. F. Spath, 'Upper Liassic Succession near Ilminster (Somerset)' in S. S. Buckman, 'Jurassic Chronology: II. Preliminary Studies' Q. J. G. S. vol. lxxviii (1922) p. 450.

[5] *Op. cit.* Neues Jahrb. Beilage-Band xxv (1908) p. 332 & pl. xii, figs. 5–6.

been mentioned that in matrix and mode of preservation *Phylloceras* aff. *mediterraneum* shows perfect agreement with *Ph.* cf. *polyolcum.* The absence of comparable *Phylloceras* from the Tithonian Spiti Shales and the Argovian beds in Kachh is noteworthy, but large, ribbed *Phylloceras* have been recorded from Callovian and Argovian beds in the Sula Islands.

The Upper Jurassic ammonites here described as *Aulacosphinctoides brownei* (Marshall), *A.* sp. indet., and *Uhligites hectori* Spath are referred to the Tithonian; but their generic identification is not definite. The very sharp ribbing of the *Aulacosphinctoides* is reminiscent of the typical Spiti-Shale forms of the group of *A. infundibulus* (Uhlig), and this is especially true of a fragment included with *A. brownei* and of an example of *A. eudichotomus* (Zittel), since sent by the Geological Survey of New Zealand. But there is also great resemblance to the genus *Torquatisphinctes* of the *acanthicus* zone. This probably includes various forms wrongly cited in geological literature as *Perisphinctes eudichotomus* and *P. contiguus*, which are Tithonian *Aulacosphinctoides*, and Waagen's *Perisphinctes bleicheri* (*non* P. de Loriol) and *P. occultefurcatus* from the Umia Beds have been provisionally referred by me to the Kimmeridgian genus *Torquatisphinctes*, on account of their resemblance to typical forms of the *torquatus* and *alterneplicatus* type. Unless both outer and inner whorls are preserved, the distinction of the various perisphinctoid genera may be extremely difficult, and the same types of suture-line, unfortunately, recur continuously throughout the Upper Jurassic.

The same difficulty is found with the form referred to *Uhligites*. Similar species, generally grouped in *Streblites*, have a wide vertical range, and W. Kilian [1] would make it persist into the Hauterivian. The Mexican forms of the group of *S. uhligi* Burckhardt [2] are probably true Kimmeridgian *Streblites*, but the secondary (peripheral) costation already foreshadows the rursiradiate ornamentation of the *Uhligites* here described. A comparable form has been recorded from the Sula Islands, where it is associated with *Blanfordiceras wallichi* and *Phylloceras strigile*, two typical Spiti forms, probably of Upper Tithonian age. If the example here described is referred to the Tithonian *Uhligites* rather than to the Kimmeridgian *Streblites*, it is on account of the peculiarly undercut external saddle and the comparatively open umbilicus.

Two more Tithonian ammonites can now be recorded from New Zealand. A specimen from Palmer Creek (Station 16–17), Awakino River, Mokau District, resembles *Virgatosphinctes discoides* Uhlig,[3] but has a distinctly flattened zone on the periphery, and is thus probably more correctly assignable to *Kossmatia* (*desmidoptycha* group); whereas another example

1 'Lethæa Geognostica: II. Mesozoicum 3, Kreide' i, 3 (1910) p. 338.
2 *Op. cit.* (Bol. No. 29, 1912) pp. 51–64, pls. xi–xv.
3 *Op. cit.* (Spiti Shales, 1910) p. 337 & pl. lix, fig. 2.

from Koutukowhai Point, Kawhia Harbour, is closer to *Kossmatia richteri* (Oppel).[1]

The genus *Berriasella*, to which *Ammonites novozelandicus* (Hauer) probably belongs, characterizes the uppermost zone of the Jurassic (*privasensis* zone), wherefore the three zones of the Tithonian, mentioned in the table on p. 304, are apparently represented in New Zealand.

Since the correlation of the beds of the uppermost Jurassic is still very uncertain, a note is here added on the upper limit of that system, so as to make clear what is meant in this paper by Tithonian. In conclusion, it may be mentioned that Uhlig[2] attached the Maori Jurassic to the Himalayan Province; but there is probably as much affinity of the New Zealand ammonites to Alpine and South American forms. When only strictly contemporaneous faunas are considered, some of Uhlig's 'provinces' cease to have any meaning; but, if I follow one great master of Ammonites, S. S. Buckman, in laying stress on the incompleteness of the Mesozoic record and in being sceptical about the influence of geographical causes, I am fully conscious of the permanent value of such monumental works as the surveys of the distribution of the Jurassic by those other great workers on Ammonites: namely, Neumayr and Uhlig.

(4) Note on the Upper Limit of the Jurassic.

Prof. A. P. Pavlow,[3] some twenty-seven years ago, in these pages gave a correlation of the boundary-beds between the Upper Jurassic and the Lower Cretaceous, and his classification is still followed in the most recent works, although he included in the Jurassic certain beds at Speeton that are really well up in the Valanginian or Lower Cretaceous. It is surprising how little is known, even at the present day, about, for instance, the supposed equivalence of the so-called 'Aquilonian' *Craspedites* zones of the 'boreal' province with the 'Lower Berriasian' or 'Upper' Tithonian of the Mediterranean area.

In the Jura Mountains, where the marine Valanginian or Lower Neocomian is underlain by freshwater beds, referred to the Purbeckian, the delimitation of the Jurassic is simple enough. But it has been held[4] that, if the original separation of the Jurassic and Cretaceous Systems had been based on the succession in the Alps, instead of on that in North-Western Europe, the Cretaceous would have been made to include the whole of the Tithonian. For the fauna of the 'Upper Berriasian' or Infravalanginian is so intimately allied to that of the Tithonian or 'Lower Berriasian'

[1] In K. A. Zittel, 'Cephalopoden der Stramberger Schichten' Pal. Mitt. Mus. K. Bayer. Staates, vol. ii (1868) p. 108 & pl. xx, fig. 10.

[2] 'Die Marinen Reiche des Jura & der Unterkreide' Mitt. Geol. Gesellsch. Wien, vol. iv (1911) pp. 389, 410, &c.

[3] 'On the Classification of the Strata between the Kimeridgian & Aptian' Q. J. G. S. vol. lii (1896) p. 548, table.

[4] E. Haug, 'Traité de Géologie' vol. ii, fasc. 2 (1907) p. 1162.

that Dr. W. Kilian,[1] the authority on the French succession, on the one hand records *Berriasella privasensis* as still occurring in the Cretaceous, and, on the other, claims the Valanginian genus *Thurmannites* also from the Tithonian or uppermost Jurassic.

Prof. Emile Haug[2] includes the 'Purbeckian' in the Portlandian as its upper, non-marine, portion, but it seems preferable to retain Oppel's term Tithonian; for, although it has been misapplied to beds the Kimmeridgian age of which was not recognized at the time, Oppel clearly meant it to be used for strata that are transitional to, or indicate the dawn of, the Cretaceous.[3]

Recent researches indicate that there is room for a very long and important epoch between the Cretaceous and the Portlandian, an epoch for the widely-scattered marine equivalents of which the terms 'Purbeckian' or 'Aquilonian' seem inappropriate. Haug's[4] opinion of the equivalence of the Tithonian, Portlandian, and Volgian cannot now be upheld, and from the appended table it will be seen that, with the Lower Tithonian below, they are here considered to represent four successive periods.

Suggested Sequence of Ammonite Zones in the Upper Jurassic.

Stages.		Zones.	Subzones.	
Tithonian.		*privasensis.*	*occitanica.*	'Lower Berriasian or Purbeckian.'
			mendozana.	
			behrendsoni.	
		pronus.	*tenuistriata.*	
			densestriatus.	
			idoceroides.	
		contiguus.	*eudichotomus.*	
			chalmasi.	
Portlandian.		*giganteus.*		
		pseudogigas.		
		gorei.		
Kimmeridgian.	Upper.	'*pallasianus.*'	*rotundus.*	'Volgian.'
			pectinatus.	
			blakei.	
		virgatus.	*virgatus.*	
			'*miatchkoviensis.*'	
			danubiensis.	
	Middle.	*steraspis.*	*vimineus.*	'Lower Tithonian' ('*acanthicus* zone').
			ulmensis.	
			bleicheri.	
			zio.	
		gigas.	*comatus.*	
			pseudopolitula.	
			subeumela.	
			pre-*gravesi.*	
		eudoxus.	*phorcus.*	
			eudoxus.	
			pseudomutabilis.	
			balderus.	
	Lower.	*tenuilobatus.*	*mutabilis.*	
			polyplocus.	
			platynota.	
			planulus.	

[1] *Op. cit.* ('Lethæa Geognostica' fasc. 2, 1910) pp. 171–82.
[2] 'Traité de Géologie' vol. ii, fasc. 2 (1907) p. 1075.
[3] Tithon was the spouse of Eos (Aurora), the goddess of dawn.
[4] 'Portlandien, Tithonique & Volgien' Bull. Soc. Géol. France, ser. 3, vol. xxvi (1898) pp. 197–228.

This sequence is based on a list given by me[1] on a previous occasion, but cannot be considered to be more than tentative; for a beginning is only now being made with the recognition of the incompleteness of the Mesozoic record, and the former view still holds sway that separate zoological provinces account for the faunal differences between, for instance, the 'Volgian' and the Tithonian. For the ammonitiferous Upper Jurassic deposits here discussed division into 'ages' based on the dominant Ammonite families, as practised by Mr. S. S. Buckman, seems to recommend itself to the specialist; but, whether we divide the Tithonian into the three zones mentioned above, retaining those that are well-known to the general geologist, or whether we change these into three corresponding ages: Berriasellidan, Kossmatian, and Aulacosphinctoidan, seems of little import. In the upper (*privasensis*) zone there is the maximum development of the family Berriasellidæ, with many new genera, including **Parodontoceras**, gen. nov., for the group of *Hoplites callistoides* Behrendson,[2] and **Protacanthodiscus**, gen. nov., for the group of *Hoplites andreæi* Kilian.[3] The genus *Berriasella* itself, with **Substeueroceras**, gen. nov. (group of *Odontoceras kœneni* Steuer[4]), ranges into the Spiticeratan age of the Infravalanginian or Upper Berriasian of some writers.

The succession of *Kossmatia tenuistriata* (Gray), *Durangites densestriatus* Burckhardt, and *Proniceras idoceroides* Burckhardt, in the zone below, is tentative, and based so far chiefly on the Mexican sequences. The abundant *Paraboliceras* of the Spiti Shales probably belong to this zone.

The *contiguus* zone is characterized by its Perisphinctids. The family Virgatitidæ, with many Portlandian and Upper Kimmeridgian genera, is replaced by the earliest Virgatosphinctidæ, notably *Virgatosphinctes*, simulating the Ataxioceratid genus *Lithacoceras* of the *ulmensis* zone below, and the genus *Aulacosphinctoides*, which has great similarity to *Torquatisphinctes* of the *gigas* ('*beckeri*' and '*acanthicus*' zones) of the Middle Kimmeridgian. Toucas's[5] *Diphya*kalk may correspond to this Aulacosphinctoidan age.

As regards the Portlandian, Salfeld[6] quotes Pavlow's beds with *Ammonites bononiensis*, *blakei*, *devillei*, and *triplicatus* as equivalents of the Portlandian, but the identifications are probably at fault. What beds of this age there may be in the Alpine-Mediterranean area have not been recognized, and may contain

[1] *Op. cit.* (Pal. Indica, 1923).

[2] In A. Steuer, 'Argentinische Jura-Ablagerungen' Pal. Abhandl. vol. vii (1897) p. 41 (167) & pl. xvii, figs. 13–15.

[3] 'Etudes Paléontologiques, &c.' in Mission d'Andalousie, Mém. Acad. Sci. Paris, vol. xxx, ser. 2 (1889) p. 670 & pl. xxxii, figs. 1 *a*–1 *b*.

[4] *Op. supra cit.* (1897) p. 45 (171) & pl. xvii, figs. 1–3.

[5] 'Etude de la Faune des Couches Tithoniques de l'Ardèche' Bull. Soc. Géol. France, ser. 3, vol. xviii (1890) table to p. 625.

[6] 'Die Gliederung des Oberen Jura in Nordwesteuropa' Neues Jahrb. Beilage-Band xxxvii (1914) table ii to p. 174.

merely the indifferent ammonite genera *Phylloceras*, *Lytoceras*, and *Haploceras*. At any rate, the zone of *Oppelia lithographica*, Haug's lowest zone of the Tithonian, contains *Waagenia hybonota* of the *steraspis* zone, and is thus of Middle Kimmeridgian age.

The Upper Kimmeridgian genus *Pseudovirgatites* has probably often been confused with the much later *Virgatosphinctes*. The other Virgatitid genera are usually believed to be confined to the 'boreal' province, and the term Volgian has been introduced for these Upper Kimmeridgian Beds. But the difficulty now arises of placing the Aquilonian, or the Russian *Craspedites* zones which are put by recent writers like Salfeld as equivalents of the Purbeckian, whereas Abel,[1] in 1897, had correlated the Upper and Lower Volgian, including the 'Riasan horizon,' with the Upper Tithonian.

The *Craspedites* zones follow on beds that have been considered to be Portlandian, though probably wrongly, as stated above. They are overlain unconformably by the Riasan Beds with a characteristic new genus of Berriasellidæ, namely **Riasanites**, gen. nov. (group of *Hoplites rjasanensis* (Lahusen)[2]), and, according to Kilian,[3] *R. rjasanensis* has been rediscovered in the Upper Tithonian of the Rhône Basin.

These *Craspedites* beds are thus well down in the Jurassic, and their ammonite fauna consists of the genera *Craspedites*, *Kachpurites*, and *Garniericeras*. In the Knoxville Beds, the genera *Durangites*, *Kossmatia*, and *Stenoceras* are associated with a '*Craspedites*' ('*Olcostephanus*' *mutabilis* Stanton[4]); but there is a contemporary of *Kossmatia*: namely, *Grayiceras* (group of *Simbirskites nepalensis* Gray sp., and *S. mexicanus* Burckhardt), which also resembles these Craspeditids. On the other hand, the *Craspedites* of the Upper Volgian are supposed to be close to those of the Riasan Beds, and Pavlow[5] recognized six species of the latter as being found also in the beds with '*Oxynoticeras*' and '*Craspedites*' *stenomphalus* of the district of Alatyr (Russia). Bogoslowski[6] thought the latter even younger, which would make them undoubtedly Cretaceous; but it may be recalled that the '*Oxynoticeras*' described by Stchirowski have also been identified with the *Garniericeras* of the Upper Volgian. In reality, there

[1] 'Die Tithonschichten von Niederfellabrunn, &c.' Verhandl. K.K. Geol. Reichsanst. Nos. 17–18 (1897) p. 360.

[2] In Bogoslowsky, 'Der Rjasan-Horizont, &c.' Mater. Geol. Russl. vol. xviii (1897) p. 142 & pl. v, figs. 3–4.

[3] 'Notice Stratigraphique sur les Environs de Sisteron, &c.' Bull. Soc. Géol. France, ser. 3, vol. xxiii (1895) p. 684.

[4] 'The Fauna of the Knoxville Beds' Contrib. Cret. Pal. Pacif. Coast, Bull. U.S. Geol. Surv. No. 133 (1895) p. 77 & pl. xv, figs. 1–5: probably three species of *Subcraspedites* (referred to *Simbirskites* by Uhlig, *op. cit.* 1911, p. 354).

[5] 'Le Crétacé Inférieur de la Russie & sa Faune' Nouv. Mém. Soc. Impér. Natural. Moscou, vol. xxi, livr. 3 (1901) p. 39.

[6] 'Materialien zur Kenntnis der Untercretacischen Ammonitenfauna von Central- & Nord-Russland' Mém. Com. Géol. St. Pétersb. n. s. vol. liv, livr. 2 (1902) table on p. 160.

is as little resemblance to *Garniericeras*, with flat and rounded umbilical border and different suture-line, as to the Valanginian *Platylenticeras* and *Tolypeceras*, with a very characteristic small first lateral lobe. Even *Garniericeras subclypeiforme* Milaschewitsch, in Nikitin,[1] which comes closest in suture-line, is merely an involute *G. catenulatum* (Trautschold), and the new genus **Pseudogarnieria** nov. (type: *Oxynoticeras undulato-plicatile* Stchirowsky [2]) is now proposed for this group. The '*Hoplites*' found in the same beds: namely, **Proleopoldia**, gen. nov. (group of *Hoplites kurmyschensis* Stchirowsky) [3] can perhaps be matched only by the Patagonian '*Leopoldia*' described by Favre [4] and by the genus *Hatchericeras* Stanton.[5] But the latter are associated with *Favrella*, which resembles *Paraboliceras*, *Kossmatia*, and *Blanfordiceras*. Uhlig [6] thought that *Berriasella* and '*Streblites*' belonged to the same assemblage, wherefore the Upper Jurassic and not Cretaceous age of the Russian beds in question is almost certain.

The three genera of the *Craspedites* beds of the 'Aquilonian' might, of course, still be considered to be boreal equivalents of such southern types as *Proniceras* and *Haploceras*, with simplifying suture-lines, and referred to the Tithonian. But it may be useful to give here a record of the sequence at Kachpur, as it appears to be represented by a number of specimens in the collection of the late J. F. Blake. There may have been confusion of beds, but the specimens are numbered in the following order :—

4–5. *Garniericeras subclypeiforme* (Milaschewitsch).
Craspedites nodiger (Eichwald).
(*Garniericeras-catenulatum* fauna missing.)

3. *Epivirgatites nikitini* (Michalski) and allies.
Epivirgatites aff. *dorsoplanus* (Vischniakoff) Michalski.
Craspedites cf. *subditus* (Trautschold).
Kachpurites fulgens (Trautschold).
Kachpurites subfulgens (Nikitin).

2. *Virgatites virgatus* (von Buch) and *Virgatites* sp.
Epivirgatites nikitini and spp.
Epivirgatites, sp. nov. (*scythicus* Michalski, *pars*).
Craspedites cf. *okensis* (d'Orbigny).
Kachpurites, sp. nov. aff. *fulgens* (Trautschold).

1. *Virgatites virgatus* (von Buch) and spp.
Bituminous Schists:
Pseudovirgatites cf. *schlosseri* Schneid, and spp.

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[1] 'Allgemeine Geologische Karte von Russland: Blatt 56' *ibid.* vol. i, No. 2 (1884) p. 149 & pl. ii, figs. 12–14.

[2] 'Ueber Ammoniten der Genera *Oxynoticeras* & *Hoplites* aus dem Nord-Simbirsk'schen Neocom' Bull. Soc. Impér. Natural. Moscou, No. 4 (1893) p. 372 & pl. xv, fig. 3.

[3] *Ibid.* p. 378 & pl. xvi, fig. 2.

[4] 'Die Ammoniten der Unteren Kreide Patagoniens' Neues Jahrb. Beilage-Band xxv (1908) pp. 624, &c. & pls. xxiv–xxv.

[5] 'The Marine Cretaceous Invertebrates' Rep. Princeton Univ. Exped. Patagonia, vol. iv, Pal. (1901) p. 41.

[6] *Op. cit.* (1911) p. 426. Uhlig also mentions a *Himalayites*: that is, *Holcostephanus hobler-hillensis* Favre; but this appears to be rather of Lower Spiticeratan (or basal Cretaceous) age.

Even supposing that the *virgatus* beds of Russia represent a condensed deposit, comprising several hemeræ of the *virgatus* and *pallasianus* zones of the table (p. 304), the *Craspedites* zones would not be higher than the Upper Kimmeridgian, if Blake's sequence is to be trusted. It may also be mentioned here that *Virgatites miatschkoviensis* which was taken by Salfeld as the index-fossil of the zone below the *virgatus* zone, shows the closest resemblance to the forms of the group of *Epivirgatites nikitini.*

It is clear that more information is required before we can correctly place the 'Aquilonian', or accept the distinctness of the boreal province, still maintained by H. Salfeld [1] who, however, claims isolation, not the existence of climatic zones, to be the cause of the differentiation of faunas.

As regards the Cretaceous beds with *Subcraspedites* of the *plicomphalus-stenomphalus* group, such as the Spilsby Sandstone, from which a form compared to the Aquilonian *Craspedites nodiger* (Eichwald) has been recorded,[2] they will be dealt with in a forthcoming paper on the succession at Speeton.

(5) Summary of New Names.

DISCAMPHICERAS, gen. nov. (p. 288).
Genotype: *Ægoceras kammerkerense* (Gümbel) Wæhner.

PARADASYCERAS, gen. nov. (p. 291).
Genotype: *Phylloceras uermösense* (Herbich) Wæhner.

PARODONTOCERAS, gen. nov. (p. 305).
Genotype: *Hoplites callistoides* (Behrendson) Steuer.

PROTACANTHODISCUS, gen. nov. (p. 305).
Genotype: *Hoplites andreæi* Kilian.

SUBSTEUEROCERAS, gen. nov. (p. 305).
Genotype: *Odontoceras kœneni* Steuer.

RIASANITES, gen. nov. (p. 306).
Genotype: *Hoplites rjasanensis* (Lahusen) Bogoslowsky.

PSEUDOGARNIERIA, gen. nov. (p. 307).
Genotype: *Oxynoticeras undulato-plicatile* Stchirowsky.

PROLEOPOLDIA, gen. nov. (p. 307).
Genotype: *Hoplites kurmyschensis* Stchirowsky.

Tragophylloceras RADSTOCKENSE, nom. nov. (p. 293).
=*Ægoceras loscombi* Wright, pars, *non* Sowerby.

Aulacosphinctoides UHLIGI, nom. nov. (p. 299).
=*Aulacosphinctes torquatus* Uhlig *non* Sowerby sp.

Aulacosphinctoides MARSHALLI, nom. nov. (p. 299).
=*Perisphinctes* sp. Bœhm.

[1] 'Die Zoogeographische Stellung des Süddeutschen Oberen Juras' Zeitschr. Deutsch. Geol. Gesellsch. vol. lxv (1913) Monatsber. pp. 441–48; also 'Das Problem des Borealen Jura & der Borealen Unterkreide' Centralbl. f. Min. &c. 1921, pp. 169–74.

[2] J. Pringle, 'Palæontological Notes on the Donnington Borehole of 1917' Summary of Progress of the Geol. Surv. for 1918 (1919) App. iii, p. 50.

EXPLANATION OF PLATES XII-XVIII.

Plate XII.

Figs. 1 *a*, 1 *b*, & 1 *c*. *Psiloceras (Euphyllites ?)* sp. nov. indet. Lower Lias. Junction of Taylor's Creek with the Otapiri, Hokonui Hills. Natural size. 1 *a* & 1 *b*, side view and cross-section; 1 *c*, suture-line, restored and magnified, Trechmann Coll. (See Appendix, p. 288.)

2 *a* & 2 *b*. *Psiloceras* sp. cf. *calcimontanum* (Wæhner). Same locality. Natural size. Side-view and sectional outline. N.Z. Geol. Surv. Coll. (See Appendix, p. 289.)

Fig. 3. *Psiloceras (Euphyllites ?)* sp. indet. Same locality. Natural size. Trechmann Coll. (See Appendix, p. 289.)

Figs. 4 *a* & 4 *b*. *Psiloceras (Euphyllites ?)* sp. indet. (juv.). Same locality. Natural size. 4 *b*, suture-line restored and magnified. N.Z. Geol. Surv. Coll. (See Appendix, p. 289.)

Fig. 5. *Rhynchonella* sp. Hettangian. Junction of Taylor's Creek with the Otapiri, Hokonui Hills. Natural size. Ventral view. Trechmann Coll. (See p. 282.)

6. *Oxytoma* sp. Same locality. Natural size. Gutta-percha squeeze of the left valve. Trechmann Coll. (See p. 272.)

7. *Oxytoma* sp. Same locality. Natural size. Left valve showing the right valve below it. Trechmann Coll. (See p. 272.)

8. *Oxytoma* sp. Same locality. Natural size. Cast of the left valve. Trechmann Coll. (See p. 272.)

9. *Oxytoma* sp. Same locality. Natural size. Cast of the left valve. Trechmann Coll. (See p. 271.)

10. *Pteria* cf. *contorta* Portlock. Slopes of South Peak, Benmore (Hokonui Hills); Rhætic (?). Natural size. Cast of the left valve. N.Z. Geol. Surv. Coll. (See p. 273.)

Figs. 11 *a* & 11 *b*. *Pleurotomaria* sp. Hettangian (?). Lower Ammonite-Bed at Taylor's Creek, Hokonui Hills. Natural size. Gutta-percha squeeze, showing the spiral and umbilical aspect. N.Z. Geol. Surv. Coll. (See p. 261.)

Plate XIII.

Figs. 1 *a* & 1 *b*. *Astarte spitiensis* Stoliczka. Bathonian–Oxfordian. Totara Point, Kawhia. Natural size. Left valve, and anterior aspect of the same. Trechmann Coll. (See p. 279.)

Fig. 2. *Astarte* cf. *sowerbyana* Holdhaus. Same locality. Natural size. Left valve. Trechmann Coll. (See p. 280.)

3. *Astarte* cf. *scytalis* Holdhaus. Same locality. Natural size. Right valve, outline restored. Trechmann Coll. (See p. 280.)

Figs. 4 *a* & 4 *b*. *Astarte (Opis ?) morgani*, sp. nov. Same locality. Natural size. Left valve and anterior aspect of the same. Trechmann Coll. (See p. 280.)

Fig. 5. *Astarte (Opis ?) morgani*. Same locality. Natural size. Right valve of another specimen. Trechmann Coll. (See p. 281.)

Figs. 6–9. *Trigonia kawhiana*, sp. nov. Southern shore of Kawhia Harbour. Natural size. Gutta-percha squeezes of the right and left valves. N.Z. Geol. Surv. Coll. (See p. 277.)

Fig. 10. *Oxytoma* sp. Southern shore of Kawhia Harbour. Natural size. Left valve. N.Z. Geol. Surv. Coll. (See p. 273.)

11. *Pecten (Camptonectes)* cf. *lens* J. Sowerby. Bathonian–Oxfordian. Totara Point, Kawhia. Natural size. Imperfect left valve. Trechmann Coll. (See p. 276.)

12. *Amberleya zealandica*, sp. nov. Same locality. Natural size. Trechmann Coll. (See p. 262.)

Fig. 13. *Cerithinella* sp. Totara Point, Kawhia. Natural size. N.Z. Geol. Surv. Coll. (See p. 262.)

14. *Pseudomonotis* cf. *echinata* Sowerby. Between Nugget Point and Catlins River. Somewhat enlarged. Gutta-percha squeeze of the left valve. N.Z. Geol. Surv. Coll. (See p. 271.)

15. *Pseudomonotis* cf. *echinata*. Same locality. Slightly enlarged. Gutta-percha squeeze of the right valve. N.Z. Geol. Surv. Coll. (See p. 271.)

Plate XIV.

Fig. 1. *Phylloceras* aff. *mediterraneum* (Neumayr) auct. Middle or Upper Jurassic. Totara Point, Kawhia. Rather more than a quarter of the natural size. Specimen with part of the body-chamber preserved, displaced at *d*. Trechmann Coll. (See Appendix, p. 294.)

2. *Aucella (?) marshalli*, sp. nov. Middle Jurassic. Sandy Bay, near Nugget Point, South Island. Natural size. Left valve. Marshall Coll. (See p. 269.)

3. *Aucella (?) marshalli*. Same locality. Natural size. Left valve with right opposed. Somewhat crushed. Marshall Coll. (See p. 269.)

4. *Aucella (?) marshalli*. Same locality. Natural size. Right valve. Marshall Coll. (See p. 269.)

5. *Aucella spitiensis* cf. var. *extensa* Holdhaus. Upper Jurassic. Waikato, South Heads (North Island). Right valve with the beak of the left valve in apposition. Natural size. Trechmann Coll. (See p. 267.)

6. *Aucella spitiensis* cf. var. *extensa*. Same locality. Natural size. Left valve. Trechmann Coll. (See p. 267.)

7. *Aucella spitiensis* cf. 'forma typica.' Same locality. Natural size. Left valve. Trechmann Coll. (See p. 267.)

8. *Parallelodon egertonianus* Stoliczka. 'Upper Jurassic.' Waikato (?). Natural size. Anterior part of a left valve. Trechmann Coll. (See p. 263.)

Plate XV.

Fig. 1. *Inoceramus* cf. *galoi* G. Bœhm. Bathonian–Oxfordian. Totara Point, Kawhia. Two-thirds of the natural size. Left valve and beak of the right valve. Trechmann Coll. (See p. 274.)

2. *Inoceramus* cf. *galoi*. Same locality. Two-thirds of the natural size. Part of a right valve. Trechmann Coll. (See p. 274.)

3. *Inoceramus haasti* Hochstetter. 'Middle Jurassic.' Kohai Point, Kawhia. Two-thirds of the natural size. Left valve. Beak missing. Trechmann Coll. (See p. 275.)

4. *Pecten (Syncyclonema)* sp. Callovian (?). Flag Hill, Hokonui Hills Natural size. Left valve (?), gutta-percha squeeze. Trechmann Coll. (See p. 276.)

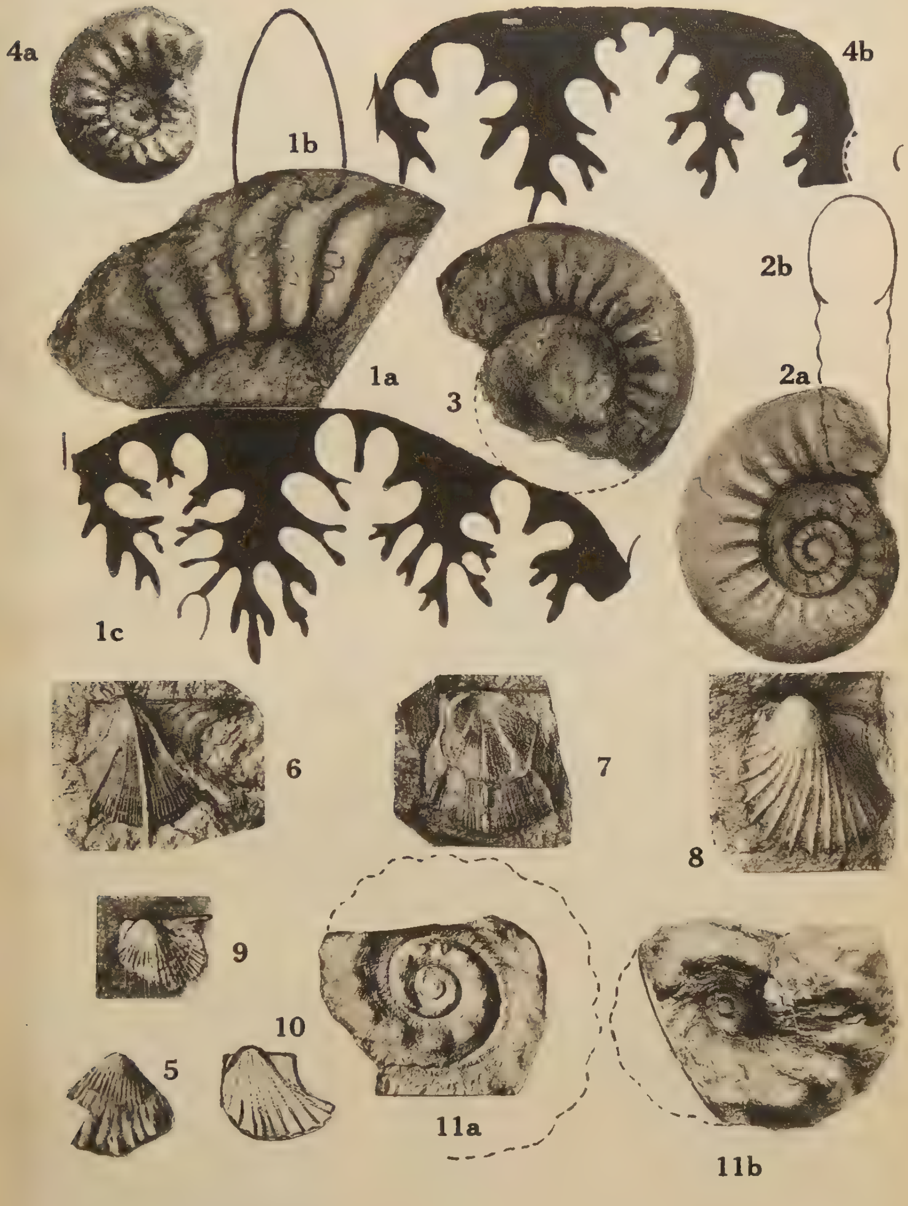
5. *Leda* sp. Callovian (?). Flag Hill, Hokonui Hills. Natural size. Right valve, gutta-percha squeeze. Trechmann Coll. (See p. 263.)

6. '*Pseudomonotis*' *marshalli*, sp. nov. Callovian (?). Flag Hill, Hokonui Hills. Natural size. Left valve. Trechmann Coll. (See p. 270.)

7. '*Pseudomonotis*' *marshalli*. Same locality. Natural size. Left valve of another specimen. Trechmann Coll. (See p. 270.)

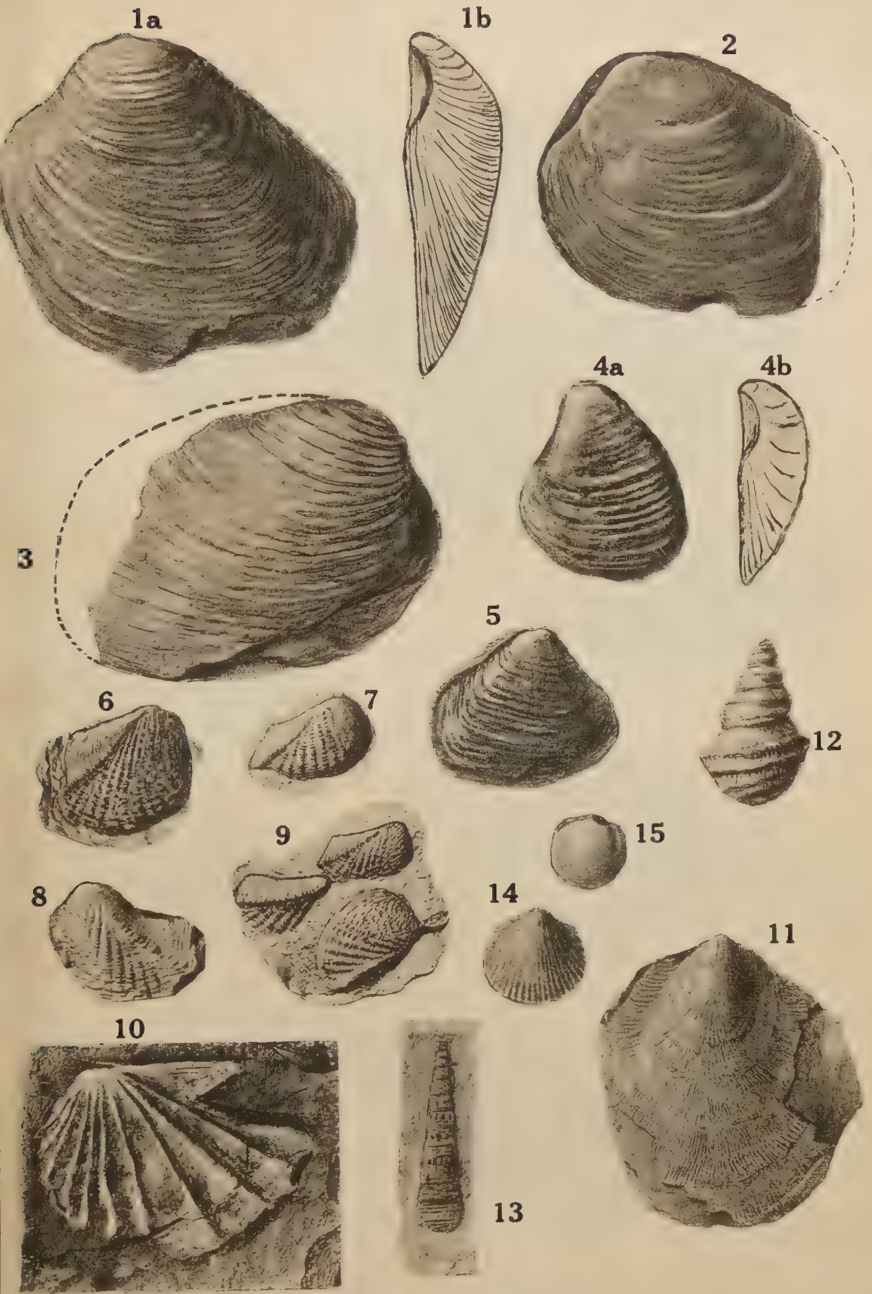
8. '*Pseudomonotis*' *marshalli*. Same locality. Natural size. Right valve. Trechmann Coll. (See p. 270.)

9. '*Pseudomonotis*' *marshalli*. Same locality. Natural size. Another right valve. Trechmann Coll. (See p. 270.)



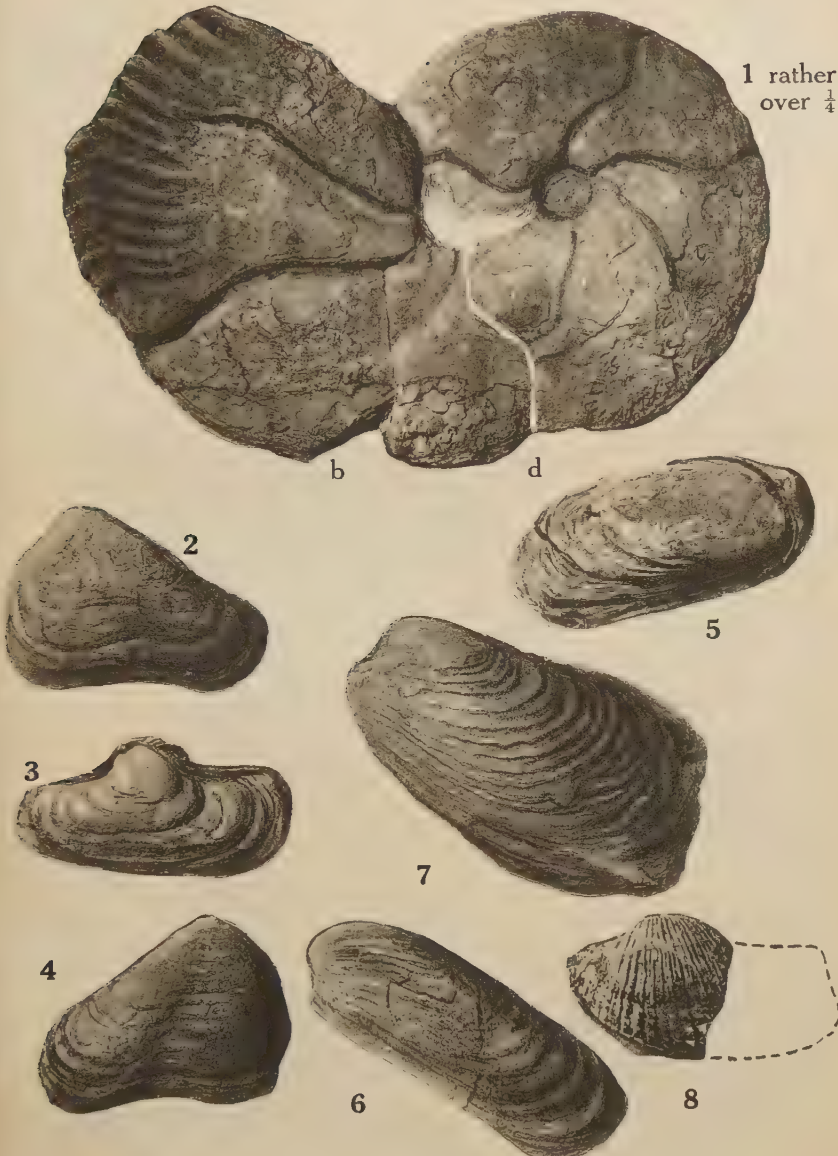
L.F.S. & C.T.T. PHOTO ET DEL.

FOSSILS FROM THE LIAS OF NEW ZEALAND.



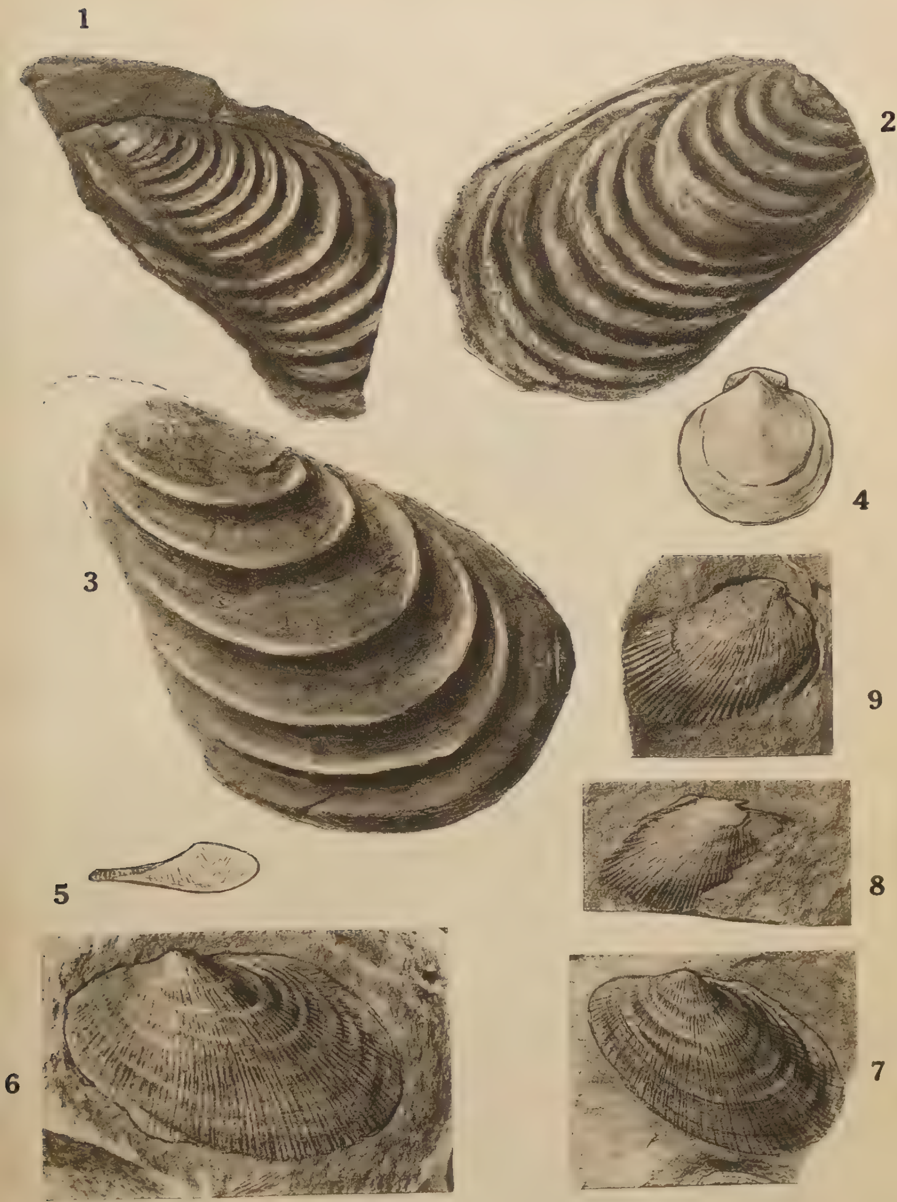
C.T.T. PHOTO & G.M.W. DEL.

MIDDLE JURASSIC FOSSILS FROM NEW ZEALAND.



C.T.T. PHOTO

JURASSIC AMMONITE AND LAMELLIBRANCHS FROM NEW ZEALAND.



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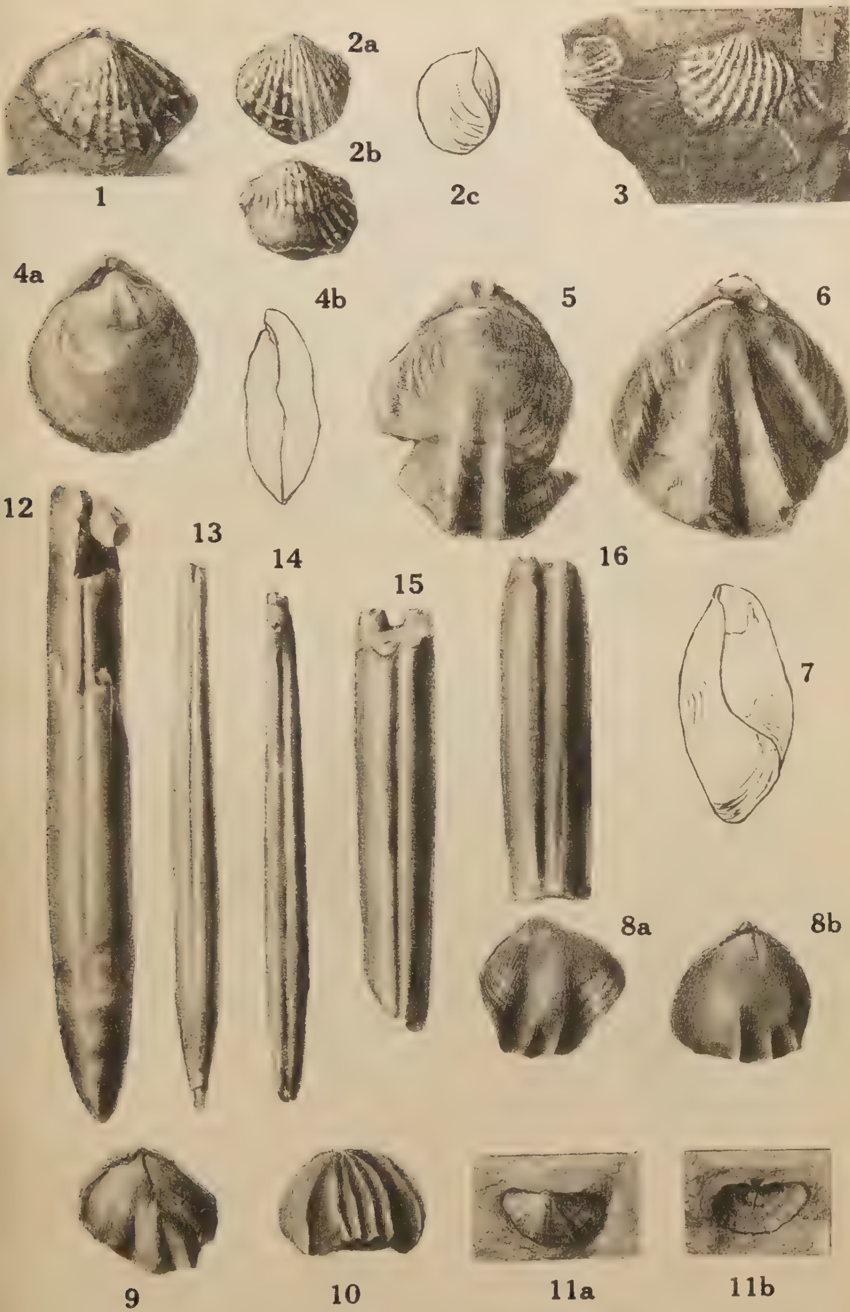
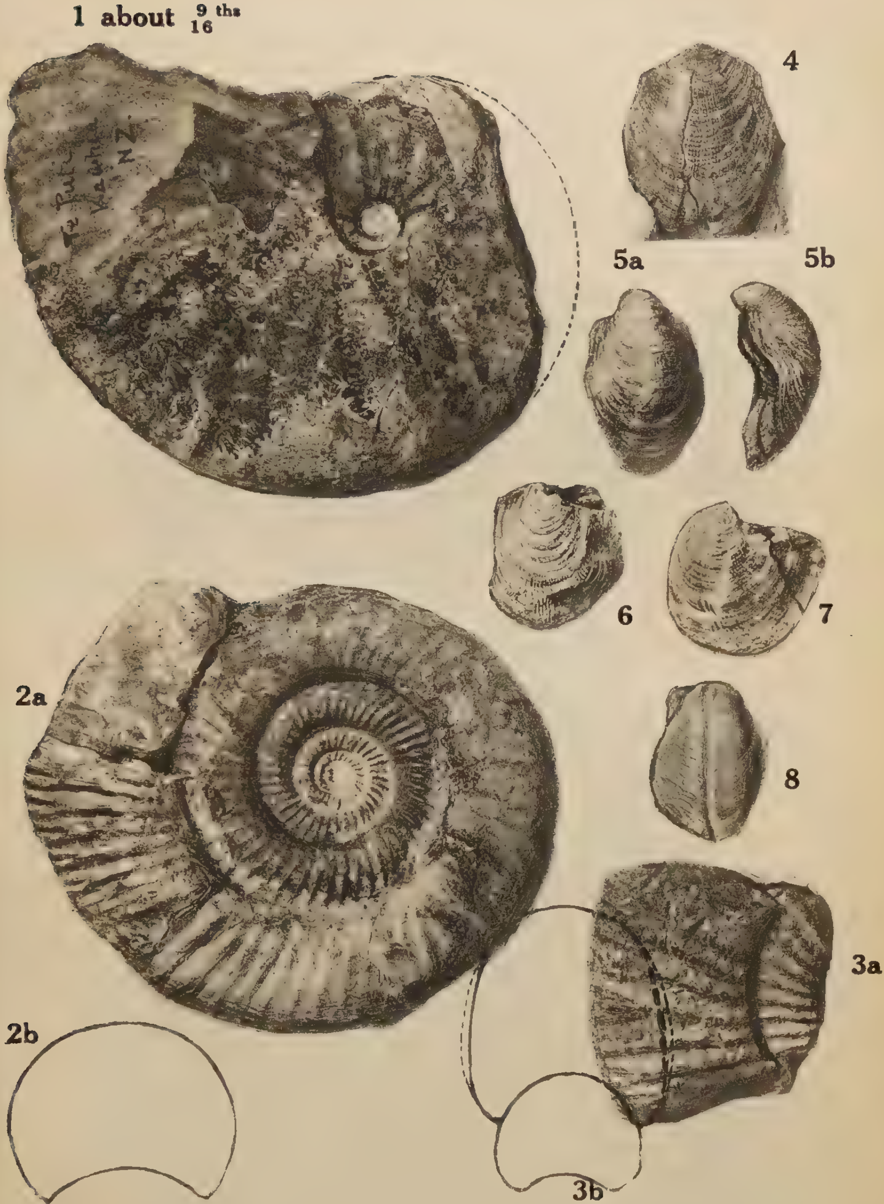
MIDDLE JURASSIC LAMELLIBRANCHS FROM NEW ZEALAND.



C.T.T. PHOTO & G.M.W. DEL.

JURASSIC BRACHIOPODS AND BELEMNITES FROM NEW ZEALAND.



C.T.T. PHOTO & L.F.S. DEL.

JURASSIC AMMONITES AND AUCELLÆ FROM NEW ZEALAND.

L.F.S. PHOTO

JURASSIC AMMONITES FROM NEW ZEALAND.

Plate XVI.

Fig. 1. *Rhynchonella (Cryptorhynchia) kawhiana*, sp. nov. Bathonian–Oxfordian. Totara Point, Kawhia. Natural size. Dorsal valve. Trechmann Coll. (See p. 283.)

Figs. 2 *a*, 2 *b*, & 2 *c*. *Rhynchonella (Cryptorhynchia) kawhiana*. Same locality. Natural size. Ventral and dorsal valves, and lateral aspect, with the spines broken off. Trechmann Coll. (See p. 283.)

Fig. 3. *Rhynchonella (Cryptorhynchia) kawhiana*. Same locality. Natural size. Crushed valves showing the long spines preserved in the matrix. Trechmann Coll. (See p. 283.)

Figs. 4 *a* & 4 *b*. *Terebratula (Heimia?)* sp. Callovian (?). Flag Hill, Hokonui Hills. Natural size. A cast of the dorsal valve and ventral beak; also lateral aspect. Trechmann Coll. (See p. 285.)

5. *Terebratula (Kutchithyris)* cf. *acutiplicata* Kitchin. Bathonian–Oxfordian. Totara Point, Kawhia. Natural size. Dorsal aspect. Trechmann Coll. (See p. 284.)

6. *Terebratula (Kutchithyris)* cf. *acutiplicata*. Same locality. Natural size. Another specimen, dorsal aspect. N.Z. Geol. Surv. Coll. (See p. 284.)

7. *Terebratula (Kutchithyris)* cf. *acutiplicata*. Same locality. Natural size. Drawing of lateral aspect. Trechmann Coll. (See p. 284.)

Figs. 8 *a* & 8 *b*. *Rhynchonella* sp. Callovian (?). Flag Hill, Hokonui Hills. Natural size. A cast rather crushed and distorted, ventral and dorsal aspects. Trechmann Coll. (See p. 281.)

Fig. 9. *Rhynchonella* sp. Same locality. Natural size. A cast, dorsal aspect. Trechmann Coll. (See p. 282.)

10. *Rhynchonella* sp. Same locality. Another cast, dorsal aspect. Trechmann Coll. (See p. 282.)

Figs. 11 *a* & 11 *b*. *Spiriferina* (?) sp. Same locality. Natural size. Ventral valve; gutta-percha squeezes of the exterior and interior. Trechmann Coll. (See p. 285.)

Fig. 12. *Belemnopsis* sp. Upper Jurassic. Te Puti Point, northern shore of Kawhia Harbour. A complete guard, ventral view. Natural size. Trechmann Coll. (See p. 260.)

13. *Belemnopsis* sp. Same locality. A complete guard, ventral view. Natural size. Trechmann Coll. (See p. 261.)

14. *Belemnopsis* sp. Bathonian–Oxfordian. Totara Point, Kawhia. Natural size. Complete guard, ventral aspect. Trechmann Coll. (See p. 259.)

15. *Belemnopsis* sp. 'Middle Jurassic.' Te Ahu Ahu, Kawhia. Natural size. Broken guard, ventral aspect. Trechmann Coll. (See p. 260.)

16. *Belemnopsis* sp. Same locality. Natural size. Broken guard, ventral aspect. Trechmann Coll. (See p. 260.)

Plate XVII.

Fig. 1. *Uhligites hectori* Spath. Upper Jurassic (Tithonian ?). Te Puti Point, northern shore of Kawhia Harbour. Lateral view, about nine-sixteenths of the natural size. Trechmann Coll. (See Appendix, p. 298.)

Figs. 2 *a* & 2 *b*. *Aulacosphinctoides brownei* (Marshall). Same locality. Lateral view and sectional outline. Natural size. Trechmann Coll. (See Appendix, p. 298.)

3 *a* & 3 *b*. *Aulacosphinctoides* sp. indet. Same locality. Lateral view and sectional outline. Natural size. Trechmann Coll. (See Appendix, p. 299.)

Fig. 4. *Aucella plicata* Zittel. 'Middle Jurassic.' Kohai Point, Kawhia. Natural size. Left valve. Trechmann Coll. (See p. 266.)

Figs. 5 *a* & 5 *b*. *Aucella plicata*. Same locality. Natural size. Left valve and anterior view of the same. Trechmann Coll. (See p. 266.)

Fig. 6. *Aucella plicata*. Same locality. Natural size. Right valve. Trechmann Coll. (See p. 266.)

7. *Aucella plicata*. Same locality. Natural size. Right valve. Trechmann Coll. (See p. 266.)

8. *Aucella plicata*. Same locality. Natural size. Left valve. Trechmann Coll. (See p. 266.)

Plate XVIII.

[All the figures are reduced to two-thirds of the natural size.]

Figs. 1 *a* & 1 *b*. *Phylloceras* aff. *partschi* (Stur MS.) Hauer sp. Lias (Middle ?), New Zealand. (B.M. No. C 5201 A.) 1 *a*, lateral view; 1 *b*, sectional outline. (See Appendix, p. 290.)

2 *a*, 2 *b*, & 2 *c*. *Rhacophyllites* aff. *diopsis* (Gemmellaro). (B.M. No. C 5200.) 2 *a* & 2 *b*, lateral views; 2 *c*, peripheral view. (See Appendix, p. 292.)

3 *a* & 3 *b*. *Thysanoceras* cf. *cornucopia* (Young & Bird). (B.M. No. C 5202.) 3 *a*, lateral view; 3 *b*, septal surface at the larger end. The impressed dorsal zone is narrow, but distinct. (See Appendix, p. 293.)

Discussion.

Dr. F. A. Bather considered that the geologists and palæontologists of both this country and New Zealand were equally indebted to the Author for so carefully collecting these specimens and bringing them to one of the great centres where they could be compared with similar fossils from other parts of the world, and thus elucidate, not merely their own affinities, but the wider problems of geology. Thus the palæontologists of New Zealand were provided with correct determinations for their fossils, and the officers of the British Museum learned the correct localities and horizons for material previously acquired under less favourable conditions. Their thanks were due to the Author and to Dr. Spath for their very careful work.

The Author expressed his appreciation of Dr. Bather's remarks, and recalled the pleasure that the collection and investigation of Jurassic and other fossils in New Zealand had afforded him. Rather than make new species, he was eager to trace the affinities of the New Zealand fossils with forms that occur in the Andes of South America, the Jurassic of Western Australia, the Malay Islands, New Caledonia (so far as that region is known), and the Kutch and Spiti Beds of India. The New Zealand Jurassic showed faunal affinity with all these regions, together with a certain individuality of its own.

13. *On a* Collection *of* Fossil Plants *from the* Falkland Islands. By Prof. Albert Charles Seward, Sc.D., Pres.G.S., F.R.S., and John Walton, M.A. (Read December 6th, 1922.)

[Plates XIX–XXII.]

Prefatory Note.

In May, 1922, I received from Dr. H. A. Baker, F.G.S., a collection of Permo-Carboniferous plants from the Falkland Islands which, with the consent of the Colonial Office, was entrusted to me for examination and description. At a later date additional specimens were received, some of which, although unfortunately too imperfectly preserved to be determined, were from rocks classed as Devono-Carboniferous. The Permo-Carboniferous material was collected on George Island and Speedwell Island off the southern extremity of East Falkland, also at North Arm, Bay of Harbours, near the southern extremity of East Falkland; while others were found at Cygnet Harbour and Egg Harbour on the western coast of Lafonia (the southern peninsula of East Falkland), and at Dos Lomas on the north-western coast.

In the examination of the fossils I have been assisted by Mr. John Walton, of St. John's College, Cambridge, who is responsible for the description and determination of the fossil wood.—[A. C. S.]

Introductory.

Subsequent to Charles Darwin's visits to the Falkland Islands little attention was paid to their geology, until the Archipelago was visited in 1901–1902 by Prof. J. G. Andersson and other members of the Swedish South Polar Expedition. The results then obtained were considerably extended by a second Swedish Expedition in 1907–1908, under the direction of Dr. C. Skottesberg. Dr. T. G. Halle, of Stockholm, who was a member of that expedition, contributed to the Bulletin of the Geological Institute of the University of Uppsala, in 1911, a very valuable account of the geological structure and history of the Falkland Islands. In a preliminary note on the flora of Graham Land, subsequently described in detail by Dr. Halle, the late Dr. A. G. Nathorst[1] mentioned the discovery by Dr. J. G. Andersson, in the Falkland Islands, of some fragmentary plant-remains which it was thought might be pieces of *Asterocalamites*. The fact that Andersson stated that the beds from which the fossils had been obtained were of Devonian age influenced Nathorst in his preference for *Asterocalamites* over *Phyllotheca* or *Schizoneura*, genera which in the character of their stem-casts closely resemble the older genus *Asterocalamites*. The specimens were shown by Nathorst

[1] Nathorst (06). Numerals in parentheses refer to the Bibliography, p. 331.

to the late Dr. E. A. Newell Arber, who believed them to be referable to *Phyllotheca*. Further examination led Nathorst to adopt this view: he did not commit himself to a specific determination, but compared them with *Phyllotheca deliquescens* (Gœppert) from Permian beds in Russia. Dr. Halle's more recent discoveries confirmed Nathorst's conclusions.

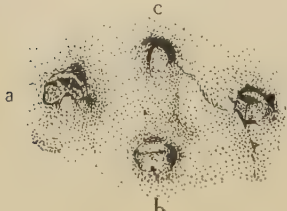
Description of the Fossils collected by Dr. H. A. Baker.

I. Devonian Plants.

Dr. Baker's collection includes a few indeterminable impressions on sandstone rocks from Port Philomel (Halfway Cove) on the western coast of West Falkland, the locality from which Dr. Halle obtained some imperfectly preserved fossils described by him as 'Lepidodendroid fragments', etc. The strata at Halfway Cove underlie marine fossiliferous beds considered to be equivalent in age to the Bokkeveld Series of South Africa. The plant-remains are carbonaceous impressions of stems, the largest of which has a diameter of 1 cm., and shows portions of lateral branches. No surface-features are visible, and identification is impossible. It is not improbable that the fossils are fragments of some Lepidodendroid plant similar to the better examples discovered by Halle and to those shown in figs. 1 & 2 (Pl. XIX).

Lepidodendroid stems.—On the north side of Port Purvis, West Falkland, a few traces of Lepidodendroid plants were collected from shale at a higher horizon in the pre-Gondwana Series. The specimens shown in figs. 1 & 2 (Pl. XIX) appear to belong to partly-decorticated stems bearing spirally-disposed leaf-scars: no surface-pattern can be detected. Both reproductions are about $1\frac{1}{2}$ natural size. The depressions are more or less circular, and have the form of obliquely sloping areas; the upper edge is more abrupt than the lower portion of the sloping floor of the depression, which merges gradually into the general level of the stem. Some of the depressions are filled with a circular patch of carbonaceous matter as in scar *b*, text-fig. 1: in scar *a* the filling material is more reniform, and a median hump or ridge is seen on the lower margin. In scar *c* the filling material is absent, and the central part of the depression is in part occupied by a projecting, blunt ridge.

Fig. 1.—*A portion of the Lepidodendroid stem reproduced in Pl. XIX, fig. 2, enlarged three times to show the leaf-scars.*



The specimen shown in fig. 1 (Pl. XIX) has a maximum diameter of 3·3 cm.; the scars are crowded, and this produces the effect of both a horizontal and a steep spiral arrangement. In some of the scars there is a median ridge as in scar *c*, text-fig. 1. It

may safely be assumed that the depressions are leaf-scars, and not the scars of roots. The broad ridge seen in several of the depressions is probably the cast of a vascular strand supplying a leaf. If the depressions were root-scars, one would expect to find a central vascular scar as in *Stigmaria*.

Dr. Halle figures some stem-fragments from Halfway Cove which he calls 'Lepidodendroid fragments': of these the smaller piece represented in his pl. vi, fig. 3,[1] agrees closely with our specimens. Halle's larger specimen differs in the more oval and elongate form of the scars, and in the presence of a small pit on the cast of each leaf-scar. It is, however, probable that despite these slight differences, Halle's specimens and those collected by Dr. Baker are portions of closely allied, or possibly identical, plants.

Lepidodendroid stems superficially similar to the Falkland specimens have been described from several parts of Gondwanaland, both from Permo-Carboniferous and from older rocks. It is noteworthy that such fossils as *Bothrodendron Leslii* Seward from the Lower Karroo beds at Vereeniging,[2] a specimen from Lower Gondwana rocks in Brazil referred by White to *Lycopodiopsis Derbyi* Renault,[3] and *Cyclostigma* sp. figured by Feistmantel[4] from a supposed Devonian locality in New South Wales, differ from the Falkland specimens in the presence in the depressions of a central pit in place of an obliquely placed cast of a vascular strand. Some of the specimens of *Bothrodendron irregulare* Schwarz[5] from the Witteberg Beds of South Africa bear, on the whole, the closest resemblance to those reproduced in figs. 1 & 2 (Pl. XIX). The possibility of affinity of the Lepidodendroid fragments to some Devonian genera other than *Bothrodendron* or *Cyclostigma* should not be overlooked, although it is clearly impossible on the available evidence to make any definite statement. Two pieces of stem from Lower Devonian rocks in Norway assigned by Halle to *Arthrostigma gracile* Dawson[6] exhibit features similar to those of the Falkland fossils, but we know nothing of the appendages which were attached to the scars of the latter. On the whole, the Lepidodendroid stem-fragments suggest comparison with the Witteberg species *Bothrodendron irregulare* Schwarz, which would be more appropriately included in the genus *Cyclostigma*, on the ground that the specimens show no trace of the ligular pit characteristic of *Bothrodendron*. In the absence of specimens showing well-preserved surface-features, the precise affinities of the Witteberg stems cannot be settled: the fossils described by Schwarz and other authors from the South African beds may not be generically identical with the European stems included in *Cyclostigma* or *Bothrodendron*.

The geological age of the Witteberg Series can hardly be determined with precision on the meagre palæobotanical evidence available. In this connexion reference may be made to some

[1] Halle (11).
[2] Seward (03) pl. xi.
[3] White (08) pl. v, fig. 11.
[4] Feistmantel (90) pl. ii, fig. 7.
[5] Seward (09) pl. xxviii.
[6] Halle (16) pl. i, fig. 8.

fossils described as *Hastimima* sp. from the Witteberg Beds of the Cape Province,[1] which undoubtedly are closely allied to specimens described by David White as *Hastimima Whitei* from the Coal Measures of Brazil, and suspected by him to be animal rather than vegetable in origin. Believing that the Brazilian and South African fossils might be portions of body-segments of Eurypterids, one of us, some years ago, submitted the Witteberg specimens to Dr. Henry Woodward,[2] who identified them as fragments of an Arthropod very similar in surface-features to the Upper Devonian species *Eurypterus hibernicus* Bail.

It is not easy, it is indeed impossible, to say with confidence whether the Falkland Lepidodendroid stem-fragments belonged to a plant more closely allied to such a genus as *Cyclostigma*, including some Upper Devonian species referred to *Bothrodendron*, or whether it should rather be compared with such older Devonian types as *Arthrostigma* and *Protolepidodendron*. The largest pre-Carboniferous tree so far described is *Archæosigillaria primæva* (Rogers)[3]—more correctly, *Protolepidodendron primævum*, as Berry has called it—from Upper Devonian rocks at Naples (N.Y.). Although not specifically identical with the Falkland fragments, this tree shows on some parts of its surface leaf-cushions similar to those shown in our text-fig. 1. *Protolepidodendron* is recorded also from the Middle Devonian of Bohemia,[4] and, as Dr. R. Kidston informs us, the genus has been recognized, although the specimens have not been described, from the Middle Devonian of Caithness.

In addition to the Lepidodendroid fragments from Halfway Cove described by Dr. Halle, which we believe to be closely allied to, or possibly specifically identical with, Dr. Baker's Port Purvis specimens, the same author figures some 'indeterminable stem-fragments' consisting of slender branched axes without appendages. He compares these with *Hostimella hostimensis* Potonié & Bernard from the Middle Devonian of Bohemia, although, as he states, actual determination is impossible. One of the branches shown in Halle's pl. vi, fig. 8 bears at the apex a globular swelling in which the central region is differentiated from the more solid peripheral portion. The account by Dr. R. Kidston & Prof. W. H. Lang[5] of the remarkable genus *Hornea* from Middle Devonian rocks in Aberdeenshire suggested to one of us a possible clue to the nature of the globular body described by Halle; it seemed possible that the central space might represent the more delicate columella-tissues of the *Hornea* sporangium. The Lower Devonian fossil *Sporogonites exuberans* Halle,[6] from Norway, is undoubtedly a spore-bearing organ similar in structure to *Hornea*. A letter written to Dr. Halle in May 1921, in which a possible relationship of his 'indeterminable stem-fragments' with *Hornea* and *Sporogonites* was suggested, elicited the following reply: 'I think it very likely that the *Hostimella*-like fossil which I have described from the

[1] Seward (09).
[2] Woodward (09).
[3] White, D. (07).
[4] Potonié & Bernard (04) p. 38.
[5] Kidston & Lang (20).
[6] Halle (16) pl. iii, figs. 10-32.

Falkland Islands belongs to the Psilophytales, either to *Hornea*, as you suggest, or to some other type.'

Other Devonian specimens are described by Halle as 'unknown plant-fragments.' These cannot be identified; but it is perhaps worthy of remark that some obscure fossils, figured many years ago by J. W. Salter as 'rootlets',[1] from the Lower Old Red Sandstone of Caithness, bear a fairly close resemblance (in the presence of more or less spherical bodies on some of the slender axes) to the fragment shown in Dr. Halle's figs. 10 & 11, pl. vi.

Summing up the slender evidence, we are disposed to consider that the balance of probability is in favour of assigning the scanty relics of the oldest vegetation of the Falkland Islands to a Devonian flora, probably a Middle rather than an Upper Devonian flora. Halle's 'indeterminable fragments' and 'unknown plants', as we have shown, bear a definite resemblance to Middle and Lower Devonian fossils of Europe, while the Lepidodendroid stem-fragments have been compared with fossils from both Upper and older Devonian rocks.

It may, at least, be said that no satisfactory evidence has been obtained of the occurrence in the Falkland Islands of a typical Upper Devonian or Lower Carboniferous European flora.

II. Permo-Carboniferous Specimens.

Some rock-structures associated with specimens of plants from North Arm, Bay of Harbours, are worthy of brief notice, because of their superficial resemblance to bulbous stems. These nodular or bulb-like bodies vary from 8 to 16 cm. in diameter, and are strongly marked out by their brown colour from the greyish-green rocks in which they occur. The sides of the 'bulbs' are smooth and slickensided, and in some there is a flat, circular area in the middle of the upper and of the lower surface. Their appearance suggests comparison with pieces of steel punched out of a thick plate. The rock would seem to have been subjected to some force acting at right-angles to the surface of the bedding. There is no evidence that plants or other organisms were concerned in the production of these curious bodies. Similar slickensided pieces of rock were described several years ago by H. B. Geinitz as fossil seeds.

Equisetaceous stems.

The collection includes several specimens of Equisetaceous stems and branches, but unfortunately no leaves or leaf-sheaths. Imperfectly preserved, detached leaf-sheaths and small leaf-bearing branches figured by Nathorst and by Halle demonstrate the occurrence of the genus *Phyllotheca*: they do not necessarily prove that all the Equisetaceous stems belonged to that type. In the absence of fairly well-preserved leaves it is impossible to

[1] Salter (58) pl. v, figs. 7*a* & 7*b*.

distinguish with confidence between stems of *Phyllotheca*, *Schizoneura*, *Neocalamites*, and *Equisetites*. *Equisetites*, a genus widely spread in the Triassic and Jurassic floras of the Northern Hemisphere, is characterized by leaf-sheaths with short, free teeth which usually lie close to the surface of the stem as in the recent *Equisetum*, and the vascular strands of adjacent internodes are alternate. In *Phyllotheca* the leaf-sheaths are similar to those of *Equisetites* and *Equisetum*, but they are often less closely appressed to the stem, and the individual leaf-laminæ are longer and more spreading. Moreover, in *Phyllotheca*, *Schizoneura*, and *Neocalamites* the vascular strands usually, though not invariably, pursue a straight course from one internode to the next. We believe that several of the specimens obtained by Dr. H. A. Baker bore leaves of the *Phyllotheca* type, but no complete leaf-sheaths have been seen on any of his material. On the other hand, we have no doubt that some specimens of Equisetaceous stems cannot be included in that genus.

(A) Equisetaceous stems. Cf. *Phyllotheca australis* Brongniart. (Pl. XIX, figs. 3, 4, & 6; Pl. XXI, fig. 16; text-fig. 2.)—Several specimens undoubtedly identical specifically with the stems referred by Dr. Halle to *Phyllotheca australis* were obtained by Dr. Baker from George Island and other localities. In view of the careful description already published, it is unnecessary to deal with the additional examples in detail. The impressions of the basal portions of leaf-sheaths are often well preserved, and these bear a striking resemblance, in the flat ribs separated by narrow grooves or ridges, to the sheaths of *Equisetum*. We have not detected any free laminæ, either as detached fossils or connected with the sheaths. The fragment reproduced in fig. 4 (Pl. XIX), nearly twice the natural size, shows a practically smooth surface: close to a very slight nodal constriction there is a row of small projecting points which may represent a whorl of slender branches. As Dr. Halle points out, M'Coy described branching stems in the Australian *Phyllotheca Hookeri* M'Coy, a species generally regarded as identical with *Ph. australis*.

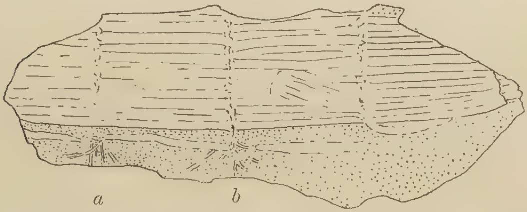
Both Nathorst and Halle compare some of the Falkland specimens with *Phyllotheca deliquescens* (Gœppert) from the Permian deposits of Russia. We are inclined to regard the slightly larger examples of Equisetaceous stems, which agree closely with those compared by the Swedish authors to the Russian species, as inseparable from the specimens included in *Phyllotheca australis*. In one of Schmalhausen's figures[1] some slender branches are seen attached to the node of a fairly large stem with prominent ribs and grooves on the internodal surface. The piece of stem shown in fig. 6 (Pl. XIX), rather more than twice the natural size, has regular ribs and grooves above the node; and on the grooves are fine longitudinal striations which probably indicate wood-elements.

[1] Schmalhausen (79) pl. x, fig. 1. (The flora, described by Schmalhausen as Jurassic, was shown by R. Zeiller to be probably of Permian age.)

On the node circular branch-scars are clearly seen. A little below the node part of a leaf-sheath is preserved: broad flat surfaces lie above the grooves on the lower level of the cast, and the smooth flat surfaces are separated by narrow grooves in each of which is a narrow ridge. The broken edge of the leaf-sheath is seen at S, fig. 6. The combination in this specimen of features shared by both forms of stem figured by Nathorst and by Halle lends support to our view that all the examples described by the Swedish authors are specifically identical, a view supported also by the branched specimen described by Schmalhausen. It is, however, hardly possible to say whether or not the Russian type is separable by any clearly defined vegetative characters from *Phyllotheca australis.*

Fig. 3 (Pl. XIX) represents part of an incomplete stem 20·5 cm. long, with internodes from 3·5 to 5 cm. long, and having a maximum diameter of 2·2 cm. The ribbing of the internodes is rather irregular, and at the nodes are branch-scars. This specimen resembles closely the larger specimens figured by Nathorst and Halle, and we see no reason for separating it from the smaller branches with leaf-sheaths. Part of a similar stem is shown somewhat diagrammatically in text-fig. 2. It is 3·5 cm. broad, and

Fig. 2.—*A cast of part of a rhizome of an Equisetaceous plant (cf.* Phyllotheca australis *Brongniart) showing roots at the nodes. Half of the natural size.*



the internodes are nearly 4 cm. long. There are indications of branch-scars on the middle node. The interesting feature of this specimen is the occurrence at two of the nodes (at *a* and *b*) of slender, branched appendages which we believe to be roots. Probably the specimen is part of an underground rhizome which bore aërial shoots agreeing with those of *Phyllotheca australis.*

The small portion of a medullary cast reproduced in fig. 16 (Pl. XXI) shows very clearly a nodal constriction, the characteristic correspondence of the ridges and grooves on the two sides of the nodes, and the impression on the internodal ridges of long and narrow wood-elements.

(B) Equisetaceous stems. Cf. *Neocalamites Carrerei* (Zeiller). (Pl. XX, figs. 8, 10, 12.)—Some of the recently-obtained stems differ in their larger dimensions, and particularly in the

narrower and more crowded ribs, from those previously recorded. A good example is shown in fig. 8 (Pl. XX). The node is marked by a slight transverse depression, *a*, on which there are faint indications of leaf-trace scars: a short distance from the node there is a much more irregular depression, *b*. The specimen reproduced in fig. 12 has the same type of internodal ribbing; but on one side of the node, and at rather a higher level on the rock, the surface is smooth, and under the microscope reveals the outlines of parenchymatous cells (text-fig. 3) which doubtless represent the epidermis. There are no traces of stomata. The epidermal features agree with those described by Halle in a specimen of the Triassic species *Neocalamites hœrensis* (Schimper) from Sweden.[1] Cells of similar size and shape are more clearly shown on a fragment, which we regard as a piece of the surface of the same type of stem as that shown in fig. 12 (Pl. XX); and their arrangement in regular longitudinal rows is a striking feature. A larger specimen of a stem identical in the ribbing with that shown in fig. 8 (Pl. XX) has an internode 9 cm. long, and is 4 cm. in diameter. The juxtaposition of two surfaces, an outer, smooth surface and a lower, ribbed cast, seen on the small piece of stem shown in fig. 12 (Pl. XX), suggested the reference to our second type of Equisetaceous stem of certain specimens with a smooth outer surface, a feature characteristic of *Neocalamites* as described by other authors. The specimen reproduced in fig. 10 (Pl. XX) shows only the outer, smooth surface: the internode above the node, a part of which is seen in the figure, is at least 8 cm. long and 3·5 cm. in diameter. Small leaf-trace scars occur at *a* on the nodal line, and at *b* there is a less regular transverse line corresponding to that seen at *b* in fig. 8. There is a very close resemblance between the stems shown in figs. 8, 10, & 12 and the Rhætic species from Tongking described by R. Zeiller as *Schizoneura Carrerei*,[2] but subsequently transferred by Dr. Halle to his new genus *Neocalamites*,[3] on the ground that the long linear leaves are borne separately and not coalescent basally into a sheath. Specimens from the Molteno Beds (Upper Karroo),[4] probably Upper Triassic in age, of South Africa, have been referred to *Neocalamites Carrerei*, and Krasser[5]

Fig. 3.—*Parenchymatous cells seen in outline on the surface of the specimen shown in fig. 12 (Pl. XX).* × *45. Cf.* Neocalamites Carrerei *(Zeiller).*

[1] Halle (08) pl. i, fig. 4.
[2] Zeiller (02–03) Atlas; (02) pls. xxxvi–xxxviii.
[3] Halle (08).
[4] Seward (03) p. 48 & pl. ix, fig. 5; (08) p. 85.
[5] Krasser (00) pl. iii, figs. 1 & 2.

has recorded similar specimens as Equisetaceous stems from strata in China considered by him to be of Rhætic age. A type of Equisetaceous stem having a smooth bark practically identical with that shown in our fig. 10 (Pl. XX) is figured by Zalessky [1] from Permian rocks of the Petchora district.

GLOSSOPTERIS. *Glossopteris indica* Schimper.

Glossopteris leaves are among the most abundant and widely-distributed of all fossil plants, but our knowledge of the morphology and affinities of the genus is very incomplete. It is probably not a true fern. In several localities, though not as yet in the Falkland Islands, *Glossopteris* leaves have been found in association with seeds, and this is almost certainly not merely accidental. In a paper communicated to this Society Dr. A. B. Walkom [2] made out a good case for connecting *Glossopteris* leaves with certain seeds which he named *Nummulospermum*, although proof of actual union is lacking. For several years palæobotanists have favoured the inclusion of the genus in the extinct group, the Pteridospermæ, which played a prominent part in Palæozoic vegetation, especially in the Northern Hemisphere.

A thoroughly satisfactory determination and specific separation of the numerous and, nearly always, incomplete leaves obtained from the different Permo-Carboniferous localities in the Falkland Islands is, we feel, a hopeless task. Most of the Falkland specimens, as Halle also found, belong to *Glossopteris indica* Schimper. A fairly large number agree more closely with the nearly allied type *G. Browniana* Brongniart. These two species cannot always be distinguished with confidence, and, until we know more about the range of variation on the same plant in the form and size of the leaves, in the pattern formed by the anastomosing lateral veins, and in the degree of differentiation of the median vascular strands into a well-defined midrib, our determinations must be, to some extent at least, provisional.

A full account of *Glossopteris indica* and *G. Browniana* is given by Dr. Halle, who records also *G. angustifolia* Brongniart and *G. damudica* Feistmantel.

Fig. 9 (Pl. XX) shows a typical leaf of *Glossopteris indica*, 9·5 cm. long, with a maximum breadth of 2·1 cm. The midrib is well marked, and the lamina tapers gradually towards the proximal end: the apex is not preserved. The meshes formed by the approximately parallel lateral veins are long and narrow, characters clearly represented in Zeiller's drawings of the type-specimen.[3] In the piece of leaf reproduced in fig. 5 (Pl. XIX) the midrib is an obvious feature, and the specimen shows an obtuse apex. An imperfect impression in Dr. Baker's collection illustrates the individuality of

[1] Zalessky (13) pl. iii, fig. 2.
[2] Walkom (21).
[3] Zeiller (96).

the midrib where it is continued below the torn lamina: the venation is of the *Glossopteris-indica* type. The venation is clearly seen in fig. 18 (Pl. XXI) on a piece of lamina 3 cm. broad: the meshes near the midrib are considerably larger than those farther from the middle of the leaf, and are less rectangular in form. This marked difference in the meshes is not a constant character, but is well illustrated by leaves of the same species from South Africa and India.

The leaf shown in fig. 7 (Pl. XIX) is probably a young leaf of *G. indica.* The collection includes several narrow *Glossopteris*-leaves identical in form with *G. angustifolia* Brongniart, as figured by Halle from the Falkland Islands,[1] and by other authors from different localities; but, in view of the occurrence of specimens illustrating a complete transition between spatulate and more linear examples, we have not adopted Brongniart's specific name. Moreover, in none of the narrower leaves that we have examined are there any distinctive venation characters other than such as one would expect in a restricted lamina. None of our leaves shows a type of venation identical with that figured by Dr. Halle as characteristic of *G. angustifolia.* A few specimens collected by Dr. Baker approach *G. damudica* in the course of the lateral veins, but we have not seen any that could be clearly distinguished in this respect as specifically different from *G. indica.*

Glossopteris indica Schimper, cf. var. *Wilsoni* Seward.

The enlarged piece of lamina reproduced in fig. 13 (Pl. XXI) differs from most of the specimens in the very small number of lateral anastomoses between the lateral veins, a feature shared by some of the leaves of *G. indica* from Antarctica named *G. indica* var. *Wilsoni*[2] and by specimens described by Zeiller[3] from the Lower Gondwana rocks of India. This variation from the normal has probably no significance in relation to geological age, and, in any case, the horizon of the plant-beds discovered by Dr. Wilson 300 miles from the South Pole has not been definitely fixed.

Glossopteris indica Schimper, cf. *G. decipiens* Feistmantel. (Fig. 15, Pl. XXI.)

The leaf reproduced in fig. 15 (Pl. XXI) differs from the great majority of specimens included in *G. indica* in having a less clearly marked midrib, except in the lower part of the lamina. In the distal portion of the leaf the highly inclined, arched veins converge towards the middle of the lamina, where they follow a vertical course; lower in the lamina the midrib becomes more distinct, and is studded with tubercles, a feature frequently seen

[1] Halle (11) pl. viii, fig. 2.
[2] Seward (14) pl. iii, figs. 11–14.
[3] Zeiller (02) pl. iii, figs. 3 & 3*a*.

on *Glossopteris* fronds.[1] A piece of the midrib is seen in fig. 17 (Pl. XXI) on a slightly larger scale. It may be that this and similar forms are specifically distinct from *G. indica* as represented by leaves with a more prominent and persistent midrib, and with lateral veins less gradually inclined towards the middle line of the leaf: the differences are at least sufficiently obvious to place on record. A comparison of the leaf reproduced in fig. 15 (Pl. XXI) with those figured by Dr. Halle from the Falkland Islands and such types as those shown in our figs. 9 & 18, raises the constantly recurring question—a question which cannot be answered with confidence in the present state of our ignorance—how much variation in venation characters may legitimately be conceded within the limits of a species? In the two forms of leaf under consideration we have, on the one hand, differences in the degree of persistence of the midrib and in the inclination of the secondary veins, and on the other the possession by both forms of the typical *G.-indica* pattern made by the anastomosing venation. A fairly considerable range in venation characters is generally admitted, and has been demonstrated in specimens which could not reasonably be assigned to more than one species. The leaf shown in fig. 15 (Pl. XXI) can hardly be referred to *Gangamopteris*: a midrib is clearly present. It may, however, be described as intermediate in venation between *Glossopteris* and *Gangamopteris*. A leaf described some years ago from Vereeniging as *Gangamopteris cyclopteroides*[2] bears a close resemblance to the slightly smaller leaf shown in fig. 15: its inclusion in *Gangamopteris* was not strictly in accord with the usual definition of the genus. Leaves figured by Feistmantel from the Karharbari Beds in India as *Glossopteris decipiens*[3] are hardly distinguishable from the specimen represented in our fig. 15. As Arber[4] pointed out, Feistmantel's species may be regarded as a type transitional between *Glossopteris* and *Gangamopteris*. Some leaves from the Raniganj Series (Damuda) of India referred by Feistmantel to *Sagenopteris*,[5] which should unquestionably be included in *Glossopteris*, afford additional examples of the same type. A comparison may also be made with an imperfect specimen from the Newcastle Beds of New South Wales, named by Feistmantel[6] *Glossopteris gangamopteroides*. Impressions from Tongking figured by Zeiller[7] present an even more striking similarity to the leaf shown in fig. 15. An example from Angaraland, probably Permian, named by Zalessky *Gangamopteris (?) angarica*,[8] cannot be distinguished from our specimen, and might well have been identified with *Glossopteris decipiens* Feistmantel.

[1] Zeiller (02) pl. ii, fig. 4; von Brehmer (14) p. 407.
[2] Seward & Leslie (08) pl. x, fig. 3.
[3] Feistmantel (79) pl. xviii, figs. 3–5 & pl. xxiv, fig. 6.
[4] Arber (05) p. 90.
[5] Feistmantel (81) pl. xlii A, figs. 1*a* & 3.
[6] Feistmantel (90) pl. xx, fig. 4.
[7] Zeiller (02) pl. xvi, figs. 2–5.
[8] Zalessky (12) pl. vii, fig. 2.

The late Prof. R. Zeiller, who spoke with exceptional authority on the taxonomy of fossil plants, included his Tongking specimens in *G. indica*, and it is noteworthy that his definition[1] of the species fits the characters exhibited by such a leaf as that reproduced in our fig. 15. *Glossopteris decipiens* Feistmantel and the leaf from Vereeniging, originally described as *Gangamopteris cyclopteroides*, are from Lower Gondwana rocks, and are associated with the oldest members of the Permo-Carboniferous flora; *Gangamopteris (?) angarica* Zalessky is from beds believed to be of Permian age, and the Tongking specimens included by Zeiller in *Glossopteris indica* are from the highest *Glossopteris*-bearing strata, probably Rhætic in age. In view of these facts, it is obvious that the type of leaf that we have called *G. indica*, cf. *G. decipiens*, cannot be regarded as a decisive criterion of geological age. It is tempting to interpret the variation from the more typical *G.-indica* type in the direction of *Gangamopteris* as evidence of greater antiquity, on the ground that leaves with a more complete midrib were probably later developments than forms without a clearly marked distinction between midrib and lateral veins. On the other hand, if the beds from which the aberrant specimens were obtained were homotaxial with the plant-beds of Tongking, one would expect to find in association with them other members of an Upper Triassic or Rhætic flora. The balance of evidence is, perhaps, in favour of assigning the type of leaf from North Arm (Pl. XXI, fig. 15) to a position below that of the beds containing the more typical examples of *G. indica*.

In the centre of an incomplete leaf reproduced in fig. 14 (Pl. XXI), identical in venation with that shown in fig. 15, there is a shallow linear depression 3 cm. long, separated by a constriction from an approximately circular and deeper depression higher on the lamina. This feature may be due to the pressure of a young and partly expanded leaf against the base of the larger frond, the deeper circular depression being the impress of the infolded apex of the immature leaf.

Some specimens collected by Dr. Baker from George Island and the Bay of Harbours are clearly identical with the single impression figured by Dr. Halle, from a locality south of Dos Lomas, as *Gangamopteris cyclopteroides* var. *major* Feistmantel[2]; but, in a few of the recently discovered examples, both the basal and the median portions of the leaf are preserved. At the base of the leaves the lamina is narrow, and there is no separation into lateral veins and midrib; but higher in the leaf a midrib is clearly shown, and the lateral veins form anastomoses of the *Glossopteris-Browniana* type: that is, the meshes are less uniform in size, and their upper and lower boundaries are not so straight as in *G. indica*. We are of opinion that if more of the specimen figured by

[1] Zeiller (03) p. 85.
[2] Halle (11) pl. viii, figs. 8 & 9

Dr. Halle had been preserved, it would have revealed a well-defined midrib.

Glossopteris Browniana Brongniart.

Leaves showing the characters of this species have been recognized from several localities, and, as already stated, some of them in the basal part of the lamina agree very closely with the incomplete specimen identified by Halle as *Gangamopteris.* None of the recently acquired material shows any features not already noticed by him in the description of the Falkland specimens.

Dadoxylon Bakeri, sp. nov. (Pl. XXII, figs. 19–22; text-figs. 4 & 5, p. 327.)

Several specimens of silicified wood were collected by Dr. Baker at Walker Creek and Fanny Cove, on the southern side of Choiseul Sound, East Falkland. They all exhibit the same characters of the secondary wood, and cannot be specifically separated. The largest piece, assuming that the pith was centric, must have belonged to a stem at least 25 cm. in diameter. Another specimen, 8 cm. by 5·5 cm. in cross-section, shows portions of the medullary and perimedullary regions. The preservation of the smaller specimen is poor, but one can distinguish in the pith and primary medullary rays large parenchymatous cells, some of which undoubtedly had a secretory function, and resemble those described by the late Miss Holden in *Dadoxylon indicum* Holden from the Barakar Beds of India.[1] There are no indications of secretory reservoirs or canals like those described by Halle in *Dadoxylon lafoniense* Halle,[2] a petrified branch from Darwin Harbour, East Falkland. Our specimen resembles the Indian stem in having a zone of tissue lining the inner side of the primary bundles, which differs from the pith and the wood in the shape and size of its constituent elements. In the Indian stem this zone consists of 'transfusion-tracheids'. It is impossible to say whether the Falkland stem agrees in this respect with *D. indicum*; but, in the appearance of the transverse sections, the two forms are strikingly alike. In transverse section the primary bundles at the periphery of the pith form rather more acute wedges than in *D. lafoniense*, *D. indicum*, and another species *D. Tchihatcheffi* (Zalessky)[3] from the Permian of Kuznetsk, which resembles our type in some other respects. Warren[4] has described a stem from the Coal Measures of Natal (Upper Ecca) in which irregularly reticulate elements occur internal to the protoxylem. He also figures[5] tracheids with pitting very similar to that observed in *Dadoxylon Bakeri*.

The secondary wood is more clearly preserved in some of the other fragments. In transverse section (fig. 22, Pl. XXII) it is

[1] Holden (17).
[2] Halle (11) pl. ix.
[3] Zalessky (11).
[4] Warren (12) p. 352.
[5] Warren (12) text-fig. 1B, p. 353.

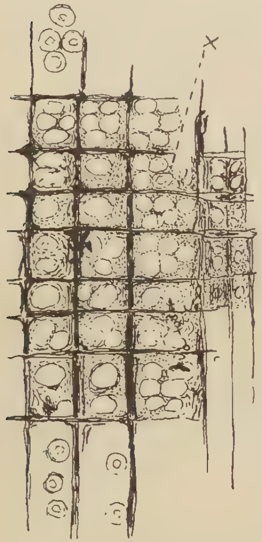
seen to be compact,[1] with distinct growth-zones varying from 0·5 mm. to 9 mm. in breadth, and resembles *D. lafoniense* very closely. The cross-sectional areas of the lumina of the spring-tracheids may be as much as ten times that of the last formed summer-elements which they succeed. This indicates well-marked seasonal phases. The tracheids are pitted on the radial walls only. The pits are bordered, and have a centric and generally circular pore. The spring tracheid-pits may be quadriseriate, but the biseriate arrangement is more usual (fig. 21, Pl. XXII). The pits are as frequently opposite as alternate. On the spring tracheids the pits are often in stellate groups (fig. 19, Pl. XXII), a feature reminiscent of *Callixylon* as illustrated by the species *C. Oweni* Elkins & Wieland.[2] In this Upper Devonian type from Indiana the pits occur in large groups, the pits in each group being frequently opposite; that is, on the same horizontal line on the face of the tracheids. In the Falkland stem the pits on the tracheids succeeding the larger spring-elements are often uniseriate and distant as in *D. Pedroi* Zeiller,[3] and in species of *Rhexoxylon*.[4] The pits on the wider tracheids are frequently polygonal when in contact, and the pore is occasionally elliptical and oblique. Trabeculæ[5] have been observed passing radially through several tracheids.

The medullary rays (fig. 20, Pl. XXII) are typically uniseriate, although biseriate rays are not uncommon. The rays vary from 2 to 16 cells in depth: the cells are thin-walled, and span 2 to 4 tracheids. Owing to the thinness of the walls the ray-pits are rarely preserved, and in radial sections one sees only the pits on the underlying tracheids (fig. 19, Pl. XXII; text-fig. 4). In one place, in the region of the summer-wood, pits on the ray-cells can be seen (text-fig. 5); they cover about half the areas of one of the bordered pits on the tracheid below the ray, and are simple and elliptical with the long axis radial. On some medullary ray-cells larger pits are shown, which are probably of the nature of 'eiporen'.

The features seen in radial section agree with those of a piece of secondary wood from Lafonia, referred provisionally by Halle to *Dadoxylon angustum* Felix. The outstanding difference is the extraordinary narrowness tangentially of the medullary ray-cells (12–15 μ) in *D. angustum*. It may, however, be added that considerable variation occurs in individual sections of some of our specimens from Walker Creek and Fanny Cove: the breadth of the ray-cells, as seen in tangential section, varies from a minimum

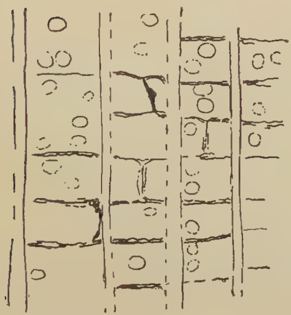
[1] Halle (11) *cf.* pl. ix, fig. 7.
[2] Elkins & Wieland (14).
[3] Zeiller (95) p. 623.
[4] Additional material of the South African genus *Rhexoxylon* Bancroft (13) from the Middle Karroo formation recently examined by one of us [J. W.] has revealed several new anatomical features; a full account of the genus will be published in the near future. [Phil. Trans. Roy. Soc. vol. ccxii (1923) p. 79.]
[5] Seward (19) p. 135; fig. 693 I (p. 137).

Fig. 4.—*Radial longitudinal section of a medullary ray of* Dadoxylon Bakeri, *sp. nov.* × *210.*



[The large pits in the field are probably simple pits on the wall of the underlying tracheids (see fig. 5).]

Fig. 5.—*Radial section of* Dadoxylon Bakeri, *showing the pitting of the medullary-ray cells above the summer-wood.* × *210.*



of 12μ to a maximum of 29μ; the tracheids flanking the rays have a breadth of 25μ and 33μ respectively.

There is a well-marked group of *Dadoxyla* characteristic of the *Glossopteris* flora in which there are clearly-defined features differentiating them from the typical Cordaiteæ. In the wood of this southern type there is no trace of a discoid pith; there is a tendency to a uniseriate and often distant arrangement of the tracheidal pits; large simple pits are found in the 'field'; well defined growth-zones often occur, and in some stems secretory cells or canals are present in the pith. In view of the uncertainty of the geological horizon of some of the southern specimens a tabular representation (p. 328) of the anatomical characters loses some of its significance; but it shows the occurrence of certain features common to a group of woods, included in the comprehensive and often imperfectly-defined genus *Dadoxylon*, found in association with *Glossopteris*.

The presence of well-marked growth-zones in these southern stems has been correlated with climatic conditions associated with the glaciation demonstrated by the widespread and thick beds of tillite in Gondwanaland. It is interesting to note that Zalessky records the occurrence of wood similar in type to those enumerated associated with members of the *Glossopteris* flora in the Petchora district, although there no glacial deposits are known.

Dadoxylon Bakeri, sp. nov.[1]

Founded on pieces of large stems. Pith parenchymatous, with a narrow

[1] While recognizing the possibility that the wood named after Dr. Baker may be identical specifically with *Dadoxylon lafoniense* Halle, additional characters shown by our material render advisable a distinctive designation.

sheath of specialized tissue internal to the primary bundles of wood which project into the medullary region. Growth-rings very distinct. Medullary rays typically uniseriate, 1 to 16 cells in depth. Tracheids with uniseriate to triseriate bordered pits on the radial walls, sometimes in stellate groups, generally in contact, but frequently distant; when more than one row of pits occur, the pits of adjacent rows may be alternate or opposite. Pits in the field simple, varying from one large, slightly elliptical pit to several smaller pits; the long axis of the ellipse is horizontal in the latter, which are pits on the wall of the ray-cell.

Locality.—Falkland Islands, Choiseul Sound. Associated with *Glossopteris*.

Name.	Horizon.	Rings.	Tracheid pits.	Pits in the Field.[1]	Pith.
Callixylon 3 spp. (North America.)	Devonian.	Slight.	1–4 rows.	Small, numerous.	...
Dadoxylon indicum Holden. (India.)	Permo-Carb. (Damuda.)	Well-marked.	1–2	Large, few.	Secretory cells.
Dadoxylon Bakeri, sp. nov. (Falkland Is.)	Permo-Carb.	Well-marked.	1–4	Large, few.	Secretory cells.
Dadoxylon Tchihatcheffi Gœppert. (Europe.)	Permo-Carb.	Well-marked.	1–3	...	Secretory cells.
Dadoxylon lafoniense Halle. (Falkland Is.)	Permo-Carb.	Well-marked?	1–2	...	Secretory cells.
Dadoxylon nummularium[2] White. (South America.)	Permo-Carb.	Indistinct.	1, distant.	...	...
Dadoxylon meridionale[3] White. (South America.)	Permo-Carb.	Absent.	1, distant.	...	..
Dadoxylon Arberi (=*D. australe* Arber).[4] (Australia.)	(Palæozoic.)	Well-marked.	1, multiseriate.	Numerous.	...
Dadoxylon sp.[5] (South Africa.)	Ecca.	Well-marked.	1–2	Large, few.	...
Dadoxylon sp.[6] Warren. (South Africa.)	? Upper Ecca.	...	1–3, often distant.	Small.	...
Rhexoxylon sp. (Africa.)	Stormberg.	Well-marked.	1–2	Large, few.	Secretory cells.

Conclusion.

I. Devonian plants.—The fragmentary remains described by Dr. Halle and the specimens collected by Dr. Baker from Halfway Cove and Port Purvis respectively, though not sufficiently

[1] Authors do not usually state whether the pits are on the tracheid or on the medullary ray-cell.

[2] White, D. (08) pl. xiii.

[3] White, D. (08) pl. xiv.

[4] Arber (05) p. 191. Reasons for substituting the specific name *Arberi* for *australe* are given in A. C. Seward's 'Fossil Plants' vol. iv (1919) p. 178.

[5] Arber (10).

[6] Warren (12) text-fig. 1 B, p. 353.

well preserved to be assigned on adequate grounds to previously-recorded species, indicate a Devonian age, and, compared with European standards, probably a Middle rather than an Upper Devonian horizon.

Seward & Walton.	Halle.
Lepidodendroid stems. Port Purvis.	Lepidodendroid fragments. Halfway Cove.
	'Indeterminable stem-fragments.' Halfway Cove. These we compare with *Hornea Lignieri* Kidston & Lang.
	'Unknown plant-fragments.' Compared by us with branched axes from the Lower Old Red Sandstone of Caithness, figured by Salter as rootlets.

II. Permo-Carboniferous plants. — The following list includes all the plants so far discovered. We have appended to some of Halle's determinations a few critical remarks:—

Equisetaceous stems.—I. Cf. *Phyllotheca australis* Brongniart and *P. deliquescens* (Gœppert). Speedwell Island; George Island; North Arm (Bay of Harbours); Dos Lomas.	*Phyllotheca australis* and cf. *P. deliquescens.* We are unable to distinguish some of the specimens from the Southern Hemisphere described as *P. australis* from *P. deliquescens.*
Equisetaceous stems.—II. Cf. *Neocalamites Carrerei* (Zeiller). Cygnet Harbour; Egg Harbour.	Not recorded by Halle.
Glossopteris indica Schimper. Speedwell Island; George Island; North Arm (Bay of Harbours); Dos Lomas; Goose Green. *Glossopteris indica* Schimper cf. var. *Wilsoni* Seward. *Glossopteris indica* Schimper, cf. *G. decipiens.* North Arm (Bay of Harbours).	*Glossopteris indica* and *G. angustifolia.* We see no sufficient reason for separating specifically the leaves so named.
Glossopteris Browniana Brongniart. George Island; North Arm; Goose Green.	*Glossopteris Browniana* and *Gangamopteris cyclopteroides* var. *major.* *Glossopteris damudica* Feistmantel.
	Coniferous twigs; cf. *Voltzia heterophylla* Brongniart. *Desmiophyllum* sp.
Dadoxylon Bakeri, sp. nov. Walker Creek and Fanny Cove.	*Dadoxylon lafoniense.* *Dadoxylon* cf. *D. angustum* Felix. The woods so named are both closely allied to *D. Bakeri.*

The Permo-Carboniferous plants do not afford any clear indication of a sequence in time of the rocks at the several localities where specimens have been obtained. The Equisetaceous stems compared with *Neocalamites Carrerei* are from Cygnet Harbour and Egg Harbour and, if our comparison is based on a real affinity, this suggests that the beds at these places may be homotaxial with Triassic strata. The other Equisetaceous stems and the two species of *Glossopteris (G. indica* and *G. Browniana)* have not only a wide geographical range, but occur in more than one

series of the Gondwana System. Excluding the possible representatives of *Neocalamites*, the flora as a whole is indicative of a position in the Lower Gondwana System, but not in the lowest part thereof. This opinion is based partly upon the absence of undoubted *Gangamopteris* leaves, and in part on the resemblance of the Falkland plants to those recorded from India, South Africa, and other parts of Gondwanaland. While recognizing that leaves of *Glossopteris*, apparently indistinguishable from some of the Falkland specimens, occur in the Rhætic flora of Tongking, we are inclined to regard the Falkland flora as homotaxial with the Damuda and Beaufort floras of Gondwanaland and with the Permian of Angaraland.

We are influenced in our estimate of the age of the plants by certain recently discovered facts, to some of which attention has been drawn by Dr. A. L. Du Toit. This author considers, and (we believe) rightly, that the recent tendency has been to assign the Lower Gondwana strata of the Southern Hemisphere to a Carboniferous rather than, as formerly, to a Permian horizon. If, as seems likely, the tillites of South Africa, South America, India, and Australia, are in the main of Upper Carboniferous age, the recent discovery by Mr. T. N. Leslie [1] at Vereeniging, of *Gangamopteris* leaves close to the old land-surface below the Dwyka Conglomerate, brings the oldest members of the *Glossopteris* flora within the Carboniferous Period. We have reproduced in fig. 23 (Pl. XXII) a well-preserved impression of a small *Gangamopteris* leaf which Mr. Leslie generously sent to one of us [A. C. S.], with other specimens discovered by him near the base of the Dwyka tillite. It shows very clearly the typical *Gangamopteris* venation: the groove near the middle of the lamina, as the veins demonstrate, does not indicate the presence of a midrib, but is purely accidental.

Similarly, the identification by Mr. H. Woods [2] of a crustacean from the Kimberley Shales as a species of *Pygocephalus*, a genus characteristic of the Coal Measures of Britain and North America, points to the same conclusion. It may be possible, by a critical review of the available data, to clarify our views on the age-relationships of the floras of the two botanical provinces: the southern province with its northward extension into Europe and Siberia, and the northern province occupied by the Permo-Carboniferous plants of Western Europe and North America. The analysis and correlation of these floras are reserved for separate treatment elsewhere. Dr. T. G. Halle draws attention to the uniformity in general character of the Permo-Carboniferous flora of the Falkland Islands, a feature borne out by the additional material obtained by Dr. Baker. Halle's conclusion, that the discovery at Dos Lomas of the leaf assigned by him to *Gangamopteris* is evidence of a geological horizon lower than that of the beds at other localities where similar leaves were not discovered,

[1] Leslie (21). [2] Woods (22).

is (in our opinion) based on the misleading appearance of the incomplete specimen which he described. We believe that his fragment is part of a leaf of *Glossopteris Browniana.* We are, however, disposed to think that the type of leaf from the North Arm beds, which we have called *G. indica* cf. *G. decipiens*, may indicate a geological age rather earlier than that of the beds from which the more typical *Glossopteris indica* leaves were obtained, as, for example, Speedwell Island, George Island, Dos Lomas. Data supplied by a comparison of *Glossopteris* and *Gangamopteris* leaves from Lower Gondwana rocks, considered in connexion with inferences drawn from a comparative study of recent Ferns, some genera of which have fronds that bear a striking resemblance to those of *Glossopteris* (a genus which was probably not a true fern), warrant the conclusion that the earlier forms of frond lacked the clear differentiation of midrib and lateral veins which characterizes the later-developed species.

In a word, we are disposed to assign the beds at Cygnet Harbour and Egg Harbour to a slightly higher position in the Gondwana System than the other plant-bearing strata, on the ground of the strong resemblance of the Equisetaceous stems found there to Triassic examples of *Neocalamites.* The beds containing the more typical forms of *Glossopteris indica*, also *G. Browniana*, and the Equisetaceous stems compared with *Phyllotheca*, we regard as homotaxial with the Damuda and Beaufort Series of India and South Africa respectively, and with Permian rocks in the Northern Hemisphere, while the beds at North Arm may be somewhat older. The wood described as *Dadoxylon Bakeri* does not in itself furnish a trustworthy criterion of geological age, as stems of the same general type range from Devonian to Upper Triassic horizons; but, in our opinion, it bears the closest resemblance to stems from the Barakar (Damuda) Beds of India and the Ecca Series of South Africa.

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EXPLANATION OF PLATES XIX–XXII.

PLATE XIX.

Figs. 1 & 2. Lepidodendroid stem-fragments. $\times 1\frac{1}{2}$ natural size. (See p. 314.)

Fig. 3. Equisetaceous stem. Cf. *Phyllotheca australis* Brongniart. Natural size. (See p. 319.)

4. Equisetaceous stem. Cf. *Phyllotheca australis* Brongniart. Natural size. (See p. 318.)

5. *Glossopteris indica* Schimper. Natural size. (See p. 321.)

6. Equisetaceous stem. Cf. *Phyllotheca australis* Brongniart. Natural size. (See p. 318.)

7. *Glossopteris indica.* Natural size. (See p. 322.)

PLATE XX.

[All the figures are of the natural size.]

Fig. 8. Equisetaceous stem. Cf. *Neocalamites Carrerei* (Zeiller). (See p. 320.)

9. *Glossopteris indica* Schimper. (See p. 321.)

10. Equisetaceous stem. Cf. *Neocalamites Carrerei* (Zeiller). (See p. 320.)

11. *Glossopteris Browniana* Brongniart. (See p. 325.)

12. Equisetaceous stem. Cf. *Neocalamites Carrerei* (Zeiller). (See p. 320.)

PLATE XXI.

[All the figures, except fig. 17, are of the natural size.]

Fig. 13. *Glossopteris indica* Schimper, cf. *G. indica* var. *Wilsoni* Seward. (See p. 322.)

14. *Glossopteris indica* Schimper cf. *G. decipiens.* (See p. 324.)

15. *Glossopteris indica* Schimper cf. *G. decipiens* Feistmantel. (See p. 322.)

16. Equisetaceous stem. Cf. *Phyllotheca australis* Brongniart. (See p. 319.)

17. Enlarged portion of fig. 15. (See p. 323.)

18. *Glossopteris indica* Schimper. (See p. 322.)

PLATE XXII.

Figs. 19–22. *Dadoxylon Bakeri*, sp. nov. Fig. 19, radial section, showing the pitting on the tracheids and in the field. $\times 210$; fig. 20, tangential section. $\times 50$; fig. 21, radial section. $\times 50$; fig. 22, transverse section showing a growth-ring. $\times 50$. (See p. 326.)

Fig. 23. *Gangamopteris cyclopteroides* Feistmantel. From the base of the Dwyka tillite, Vereeniging. Natural size. (See p. 330.)

14. Further Researches *on the* Succession *and* Metamorphism *in the* Mona Complex *of* Anglesey. By Edward Greenly, F.G.S. (Read March 28th, 1923.)

Contents.

Since my return to North Wales, the proximity of Anglesey has made it possible (in intervals of my survey of the country about Bangor and Carnarvon) to seek further light on the unsolved problems of the Mona Complex; and some of the results are embodied in the present paper.[1]

I. The Age of the Mona Complex.

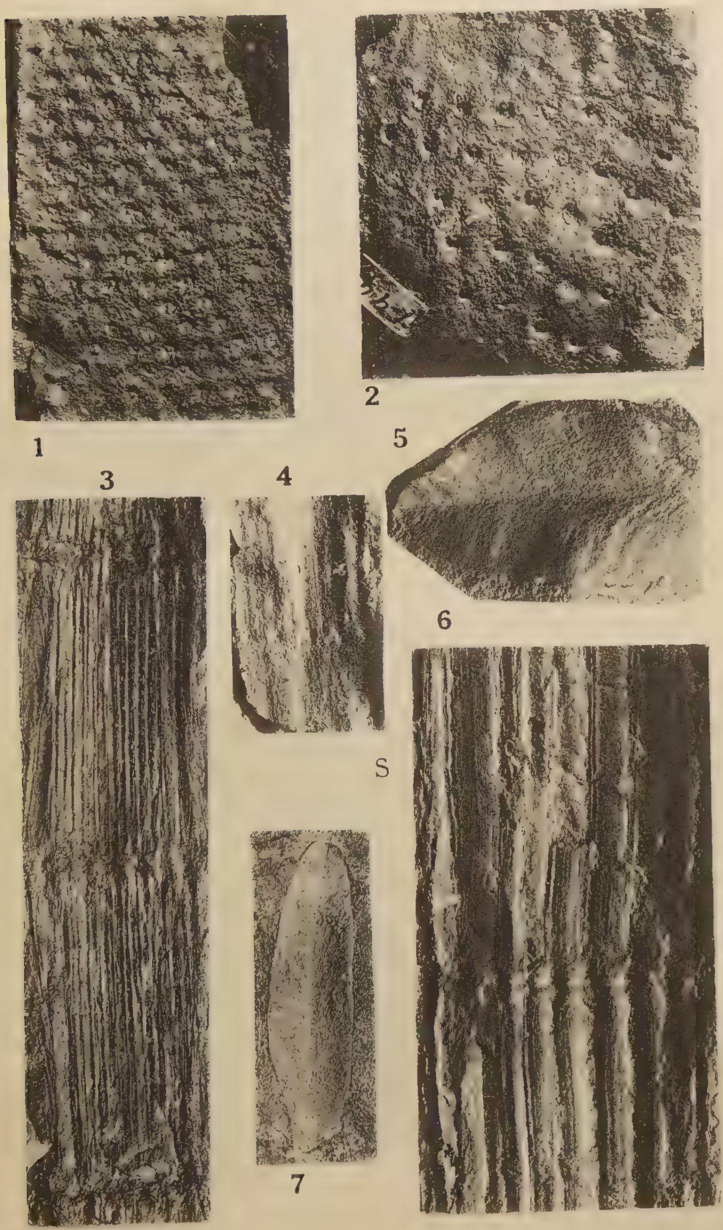
Pebbles derived from the Mona Complex had already been found in Cambrian rocks[2] ranging from the Bron-llwyd Grit down to the basement conglomerates of Carnarvonshire. Fragments have now been obtained from much lower horizons. For the massive conglomerate of Bangor cannot be later than Cambrian, and it is certain that, at any rate, the lower portions of the Bangor Volcanic Series (with which portions alone we are concerned in this paper) must be much older than that conglomerate.[3] The Volcanic Series being essentially pyroclastic, fragments other than those of the contemporaneous volcanic rocks are rare. The agglomerates, however, have yielded a few fragments of Gwna quartzite and jasper. These fragments are not schistose. But in a slide [E 1539],[4] cut from an agglomerate between the Workhouse and Hendre-wen Lane, there is a beautiful oval fragment (fig. 1, p. 335), about $\frac{1}{8}$ inch long, of undoubted Penmynydd-Zone mica-schist, well-foliated and holocrystalline, with sphene, zircon, and a pale

[1] The Geological Survey Memoir entitled ‘The Geology of Anglesey,’ 1919, will be referred to in this paper as ‘G. of A.’

[2] ‘G. of A.’ pp. 246–52.

[3] I have now mapped most of the Bangor area; but, until the whole of that area is surveyed, it would be premature to discuss the question of unconformity between the conglomerate and the Volcanic Series. It may, however, be said that evidence only available lately has revealed unsuspected complications.

[4] The slide-numbers quoted are those of the Geological Survey Collection.



J.W. & W.T. PHOTO.

LEPIDODENDROID AND EQUISETACEOUS STEMS; GLOSSOPTERIS.

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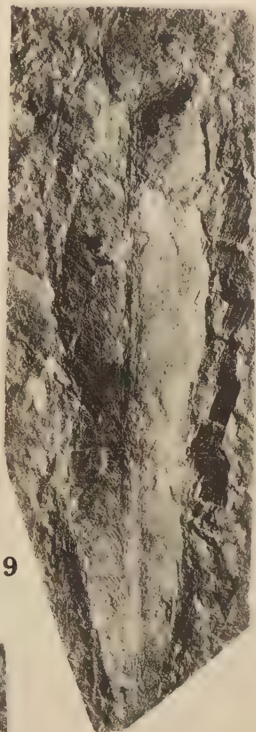

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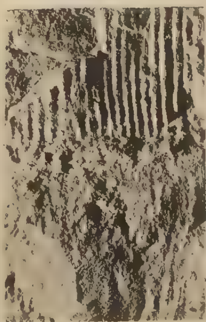
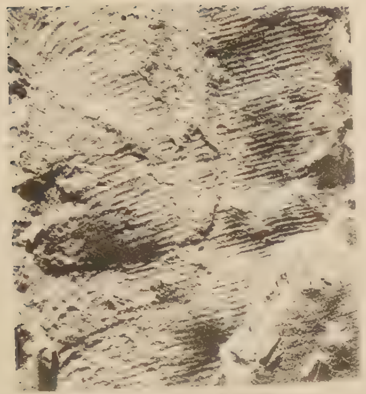


J. W. PHOTO.

EQUISETACEOUS STEMS; GLOSSOPTERIS.



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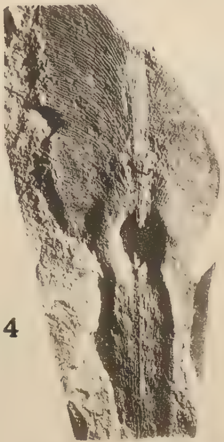

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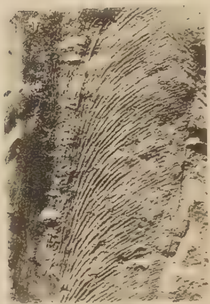

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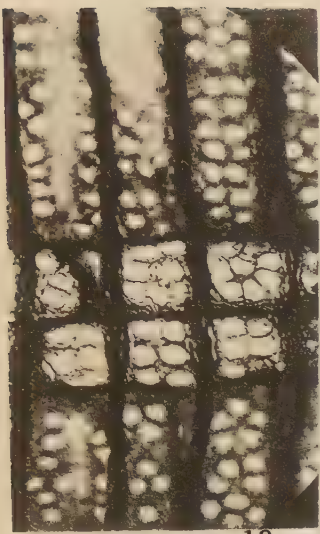
J.W. & W.T. PHOTO.

GLOSSOPTERIS ; EQUISETACEOUS STEM.



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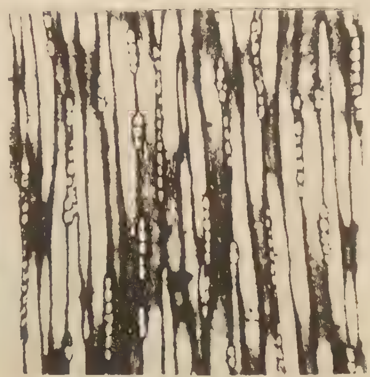

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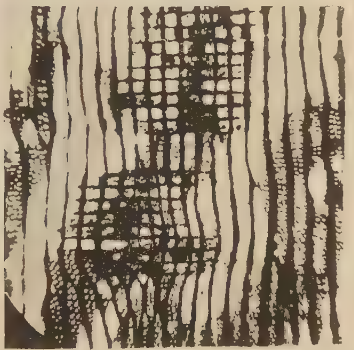

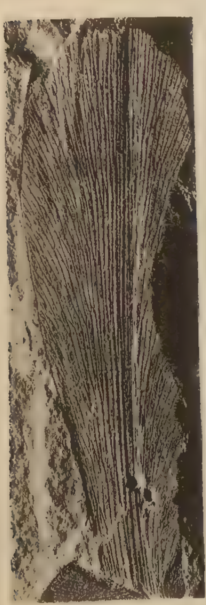

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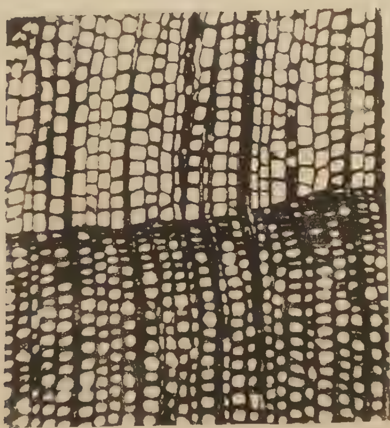
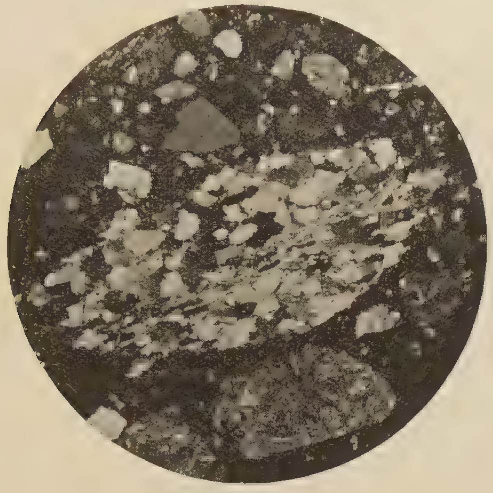


J. W. PHOTO.

DADOXYLON BAKERI ; GANGAMOPTERIS.

epidote. It is, therefore, certain that, before the eruption of this ancient volcanic series, the Penmynydd anamorphism of the Mona Complex was complete.

Fig. 1.—*Fragment of mica-schist in an agglomerate of the Bangor Volcanic Series.* × 19.



II. The Gwna Beds.

New Analyses of the Quartzite.

At the time of the issue of the Geological Survey Memoir, only one analysis of a Gwna quartzite was available. Owing to the kindness of Mr. W. B. Hartley, of the United Silica Company, I am now able to communicate four analyses of the quartzite of Graig-wen in Gynfor; while Mr. F. Russell, of the General Refractories' Company, has kindly supplied one of that at Llangefni:—

	I.	II.	III.	IV.	V.	VI.
SiO_2	95·98	94·11	94·53	96·80	97·88	95·86
TiO_2	...	...	...	0·16	0·05	0 04
Al_2O_3	0·75	2·70	2·61	1·74	0·92	1·75
Fe_2O_3	0·63	0·20	0·27	0·40	0·23	0·35
CaO	0·33	0·34	0·36	0·04	0·12	0·24
MgO	...	0·23	0·02	0·03	0·08	0·07
K_2O	1·20	0·92	0·64	0·48	0·26	1·13
Na_2O	0·84	0·50	0·58	0·24	...	
SO_3	...	0·64	0·23	...	...	·17
Loss over 109°	0·36	0·50	0·54	0·36	0·38	0·43
Totals	100·09	100·14	99·78	100·25	99·92	100·04

MnO, P_2O_5, CO_2, and C not found.

I–IV. Quartzite of Graig-wen in Gynfor, near Porth-wen Bay on the northern coast. [See slides E 10953–54, also 10951, 10955.] 'G. of A.' pp. 79, 311. Anal. Dr. J. W. Mellor.

V. Quartzite of Llangefni Old Windmill (Graig-fawr Windmill of the 6-inch map), an inlier among Carboniferous rocks. [E 9954, 10696.] 'G. of A.' p. 350. Name of analyst not stated.

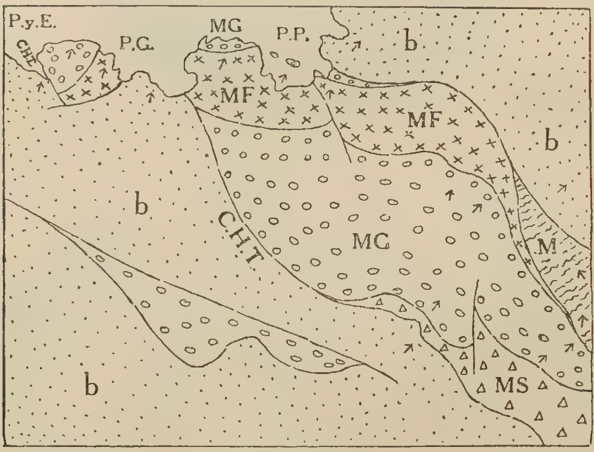
VI. Average of Analyses I–V. If, also, we include the two silica-percentages (96·40 and 99·60) mentioned in 'G. of A.' p. 79, then the average percentage of silica is 96·47.

The apparently capricious alkali-percentages are due to planes which carry films of a white mica.

III. The Fydlyn Beds.

Mynachdy.—When the Survey Memoir and 1-inch map were published, Fydlyn Beds had not been recognized with certainty in the northern region. In November, 1921, however, while I was

Fig. 2.—*The Fydlyn Beds at Mynachdy (from the 6-inch maps).*



b = Ordovician.
MS = Church Bay Tuffs.
MG = Gwna Beds.
MF = Fydlyn Beds.
M = Gneisses.
C.H.T. = Carmel-Head thrust-plane.
P.y.E. = Porth-yr-Ebol.
P.G. = Porth Gron.
P.P. = Porth-padrig.

re-examining the perplexing coast-sections between Porth-yr-ebol and Porth-padrig, Mynachdy, some of the 'confused types' ('G. of A.' p. 295) struck me as so like the Fydlyn rocks that I wondered that I had not suspected their identity before. The result of comparison with Fydlyn and of subsequent re-examination was decisive. The rocks, though much decomposed, and rather

more ferruginized, resemble those of the Fydlyn coast in every particular. The massive rhyolitic types with rounded quartz, and the pyroclastic varieties, are both present. They are highly felspathic, often weathering just as white,[1] and there is the same sporadic silicification, while deformation is not excessive.[2] The rhyolitic series first appears on the coast at the back of the eastern cove of Padrig, whence (interrupted in Porth Gron by the Carmel-Head thrust-plane) there are excellent sections as far as the western walls of that cove. Perhaps the finest is on the eastern crags of Gron, where one might imagine oneself on Fydlyn south cliff; the same white felspathic varieties with rounded quartz, and weathering into cavities, being evidently rhyolites, while pyroclastic types come on to the south of them. With microscopic examination all doubt vanishes. The more massive types are composed of a microfelsitic matrix (micacized and silicified) wherein are phenocrysts of quartz and felspar. The others—such as the 'massive grit' of Porth Gron ('G. of A.' p. 295)—are dust-rocks (highly micacized) with numerous irregular angular fragments of quartz, felspar, keratophyre, and rhyolite. Such felspars as yield good optical reactions are albite. Finally, they contain the same opaque yellowish-white leucoxene as has now proved to be persistently present at Fydlyn.[3]

Most important, however, is the fact that here, as at Fydlyn, they adjoin the Gwna Beds, their gradation into which by alternation with thin grits (now cut up into mélange) is even better exposed, and much more accessible. The zone of gradation, about 10 feet thick, is perfectly clear at a cave's mouth between the coves of Padrig, on both sides of the western Padrig inlet, along the shelf (below boulder-clay) which runs along the sea-cliff thence to Porth Gron, and on the eastern crags of that inlet.

Wylfa.—The suspicion that the rocks by the Lifeboat Station might be the Fydlyn Beds ('G. of A.' p. 308) has been confirmed. Although much ferruginized, they are quite white in many places. The type containing rounded grains of quartz, like those of rhyolites, can be identified. Other varieties have the characteristic micacized matrix, crowded with angular pyroclasts of quartz, alkali-felspar (some of which is determinable as positive), keratophyres, and rhyolites; they are manifestly rhyolitic tuffs. Leucoxene is also present. Thin bands of grey shaly matter, which resemble those of Fydlyn beach, though excessively shattered, preserve the bedding for a few inches at a time.

[1] The silica-percentage of a rhyolitic tuff from Fydlyn south cliff [E 12362], kindly estimated by Mr. Roberts, Lecturer in the University College of North Wales, is 69·38.

[2] Fig. 2 (which should be compared with the 1-inch map, and with 'G. of A.' folding-plate xiii) shows the alterations in the map which this discovery has involved.

[3] Even these rhyolitic lavas thus partook of the generally high titanium-content of the Mona Complex.

Bull Bay.—The white schists of the western cliffs of this bay ('G. of A.' pp. 312–15) must also be regarded as Fydlyn Beds. They are often as white as at Fydlyn, and weather in the same manner, but are more schistose. Under the microscope, we find the characteristic microfelsitic matrix, now highly micacized. Some are pyroclastic, but one of them retains (although its matrix is now a micaceous schist) some of the characters of a porphyritic rhyolite, with subquadrate phenocrysts of quartz and many of unquestionable albite in tolerably good preservation. Granules of leucoxene are also present.[1]

Stratigraphical considerations.—The identification of Fydlyn Beds at Mynachdy, Wylfa, and Bull Bay is of the greatest importance. For, as they adjoin the Gwna Beds and pass gradually into them, the hypothesis that they are the lowest-known member of the Bedded Succession is confirmed (see also p. 342). Further, in view of the magnitude of the Carmel-Head thrust-plane, on both sides of which they are now known, it is evident that they are no mere local development, but an horizon of widespread volcanic activity of rhyolitic type. Moreover, this makes their identity with the great mass of the Penmynydd-Zone mica-schist more probable than ever.

Regional tectonics.—Their relationships also confirm the view ('G. of A.' pp. 177, 215–16) that the succession in the Northern Region is inverted. For, if we compare their condition, at all three places, with that of the rocks which occur on the other side of the Gwna Beds, it is evident that anamorphism is waning as we pass from younger to older members of the succession.

Local tectonics. (1) Mynachdy.—It will be seen (fig. 2, p. 336) that there are two tracts of Gwna Beds above the Carmel-Head thrust-plane. One is a narrow fringe along the coast; the other is inland, Church Bay Tuffs (which have lately been separated out on the maps) rising to the south of it. The Fydlyn Beds lie between these two tracts, and, as the Gwna Beds of the inland area are unusually felspathic along their northern margin, it is evident that the Fydlyn Beds can only be a few yards away, and must be bending round south-eastwards. Now, if, as has been urged, the succession be inverted, the Fydlyn Beds must be taken in on a major isoclinal infold ('G. of A.' p. 217). In and west of Porth Gron, the southern limb of this infold is cut out by coming on to a bend in the Carmel-Head thrust-plane; while, east and south-east of Porth-padrig, its northern limb is cut out by the Padrig slide. But it must have an eastward pitch, for in that direction the Mynachdy gneiss appears, and must occupy the core of the infold. Where Gwna Beds reappear beyond the gneisses east of Mynachdy, however, no Fydlyn Beds have been detected, and the northern limb of the infold must be cut out once more;

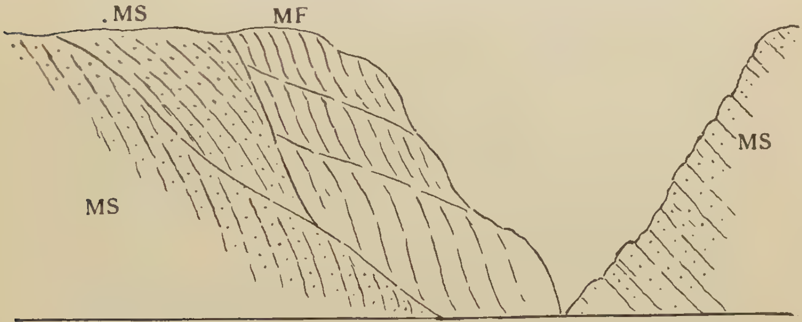
[1] The slides of these Fydlyn rocks are E 12362–66, 12368–71.

not, however, by the Padrig slide, but by thrusting at a lower angle than the major axis. This phenomenon is seen on a small scale, on the same northern limb, along the coast, where the Fydlyn-Gwna zone of passage is partly cut out several times by just such thrusting, which drives the Gwna Beds over it—thus restoring, locally, the chronological order of succession.

(2) Wylfa.—The Fydlyn Beds, readily decomposing, have weathered into a grassy curving hollow, running westwards across the neck of the headland. Of the fact that the succession is inverted, we have (p. 341) independent evidence. Here again, therefore, a major isoclinal infold is revealed, its core being occupied by Fydlyn Beds. I am now, however, convinced that it is ruptured on, at any rate, its southern side. The Fydlyn Beds of the core fail to emerge in Porth-wnol, where they come on to the Wylfa thrust-plane ('G. of A.' pp. 218–19 & fig. 96) at a lower angle than the isoclinal axis. Further, as there is a considerable angular divergence between the strike of the infold and that of the thrust, it would appear that they are tectonically unconnected, and that the infold is the older structure of the two.

(3) Bull Bay.—A few paces inland, Gwna Beds are only 17 yards away across the strike, but they just fail to reach the cliff, with the result that Fydlyn Beds are there brought against the Church Bay Tuffs. The difficulty of postulating a rupture too large to be credible at this place can now be removed. The cliff-section, which is 50 to 60 feet high, is represented in fig. 3.

Fig. 3.—*Cliff-section at Bull Bay.*



MF=Fydlyn Beds. MS=Church Bay Tuffs.

Let us interpret it also on the hypothesis that throughout the region the succession is inverted, and that the Gwna Beds have been reduced in thickness by the local waste whereof the pebbles in the Skerries Group are evidence. Suppose, then, that a major isoclinal infold containing Gwna Beds is pitching eastwards, so as to be just bringing in Fydlyn Beds[1] at the meridian of the present

[1] Revision of the 6-inch map favours contact of the two series for a short distance inland.

coast-line. Suppose this infold to be cut by ruptures due to the tendency to subsidence on pitch, and these again by thrusts whereon the narrow core of Fydlyn Beds was driven at an angle of about 30°, on to the Church Bay Tuffs of the outer part of the southern limb of the infold. There would then eventuate the relations which are seen in the cliff, and we can thus also account for the infold contracting, instead of expanding, in the direction of the pitch.

IV. The Penmynydd Zone of Metamorphism.

(1) The passage from the Gwna Mélange to the Penmynydd Zone.—Another section across this passage has lately been discovered on the Aberffraw coast. In the nook of the bay north-east of Bryn-llwyd, about 30 to 50 yards east of the passage on the buttress already described ('G. of A.' foot of p. 124), the Gwna mélange contains augen of a reddish grit and of a brown limestone. Yet, only 4 feet from them across the strike, Penmynydd-Zone mica-schist appears, with well-developed micas, the quartz and the limestone becoming saccharoidal, while rapid minor folding also sets in. More still: the fissile matrix of the adjacent grit-augen is found on examination to have already become a true mica-schist. We have, therefore, here a real inlier of the Penmynydd Zone, although only about 10 feet thick at its outcrop, and no better exposure of the passage to the Penmynydd Zone is known in the Mona Complex. Re-examination of a slide (E 6139, from the western cliffs of the bay) gives further confirmation. The greater part of the slide is a calcareous Gwna Green-Schist, yet at one side of it is a band brilliant with white mica, some crystals of which are 1 mm. long and 0·25 mm. broad. The Penmynydd-Zone anamorphism is therefore selective, developing in seams already rich in the elements of mica, while closely adjacent seams of different composition are still at the stage of Gwna Green Schist. The remarkable rapidity of the passage, in both cases, confirms the suggestion ('G. of A.' p. 127) that dynamic metamorphism was facilitated by change of material, as well as of conditions.

(2) The hornblende-schists.—At the 178-foot level east-north-east of Plas-berw, and at several other places, these rocks contain ('G. of A.' pp. 114–15) many quartz-albite augen, which by waning of albite pass gradually into ordinary quartz-augen. That they belong to the metamorphic process is certain, for some of them are foliated internally, while others are cased in a film of paragonite. The stage at which they developed was a late one, for some of them truncate the foliation, though slightly. Yet it was not the final anamorphic stage, for these schists are cut and shifted by foliated quartz-veins containing needles of hornblende, which are dynamically connected with the transverse folding. That these augen are segregations is abundantly evident from their general relations. It is, therefore, of much interest to find

that the hornblende-schist in contact with them is nearly always much more basic than it is elsewhere. Judging by its coloration one would estimate that it is often twice as basic. In the same rock there are many bands of the compact siliceous schist which is regarded ('G. of A.' p. 121) as of adinolic nature; but these have no dark encasements, reaction-rims, indeed, being sometimes developed. Thus, where the siliceous inclusion is a xenolith, the hornblende-schist is either unaffected, or slightly robbed of basic matter: where the siliceous inclusion is a segregation, it is robbed of acid matter.

V. The Age of the Gneisses.

Clastic oligoclase.—This felspar has been found in the New Harbour Beds, the Church Bay Tuffs, and the Gwna Beds. But, in the Mona Complex, authigenic oligoclase is known only in the gneisses, where it is a persistent feature.

Characters in the different regions.—The process of development of the basic gneisses (pp. 343–49) was the same, even down to minute details, in the Middle as in the Aethwy Region. This indicates that these rocks are not mere modified forms of local intrusions, but that they belong to a widespread gneissic formation.

Relations to the hornfels.—Mica-hornfels of the Coedana Granite occurs within a yard or two of gneiss at Gwyndy ('G. of A.' pp. 162, 334). A slide cut by J. F. Blake [E 10680] has now, by comparison of maps, been found to be from this place. It is quite unfoliated, with large porphyroblasts of intergrown muscovite and biotite, and it contains orthoclase, which indicates its independence of the Gneisses. Moreover, 217 yards away to the north-east, compact cryptocrystalline hornfels occurs only 50 yards from gneiss. Mica-hornfels ('G. of A.' pp. 162, 322, 333) has now been found on the north side of the main Holyhead road, between Caer-glaw and the 9th mile-post, only 30 yards from typical gneiss, and not separated therefrom by the Treban Fault.

Relations to the Gwna Beds.—Re-examination of the three granitoid masses of Mynydd Wylfa ('G. of A.' p. 307) reveals that the southernmost has a strong lenticular foliation; also, that along its southern margin there are a few feet of basic gneiss, heavily crushed, but retaining survivals of banding, pegmatitic seams, and crystalline junction with the granitoid rock, as well as a 1-foot band of a coarse acid gneiss. No doubt, therefore, need remain that these rocks belong to the Gneisses. The larger of the two northern masses ('G. of A.' fig. 139) can be seen to overlie Gwna Beds wherein anamorphism is almost imperceptible.[1]

Relations to the Fydlyn Beds.—On the view of the general succession which has been adopted, the Fydlyn Beds might

[1] No Fydlyn Beds could be found, so they are evidently (p. 339) cut out.

be expected, wherever the Gneisses and the Gwna Beds occur together, to intervene between those formations. No gneisses have been found at Fydlyn; and at Mynachdy, where they do occur, it was inferred that the Fydlyn Beds must have been cut out ('G. of A.' p. 216). The result set forth in this paper (pp. 336–38) throws a flood of light on the whole question. In the first place: as Fydlyn Beds have now been identified at Mynachdy (fig. 2, p. 336),[1] in the very position where they were to be expected, my reading of the succession is confirmed. In the second place: the contrast between their crystalline condition, which is but slightly anamorphic, and that of the Gneisses with their large plutonic albites and large biotites in the foliated bands, is extreme. The two conditions belong to widely separated zones of the lithosphere, and cannot be genetically connected. In the third place: the Gneisses, as highly crystalline as anywhere in the island, keep on (fig. 2) striking at the boundary.

Finally, a rhyolitic tuff of the Fydlyn Beds [E 12362] has yielded a fragment of plutonic mosaic through which runs a folium with parallel flakes of a white mica, and thus of gneissose character. This specimen, which is from Fydlyn south cliff, was obtained at a point about 150 feet below the base of the Gwna Beds, the lowest horizon at which any derivative composite fragment had hitherto been found, and therefore a long way below the only admissible break in the bedded succession.

Secondary dynam-anamorphism.—It has been stated ('G. of A.' p. 168) that, at Mynachdy, the Gneisses are wholly catamorphic. But a coarse albite-granite of the gneiss [E 10642], from near the junction with Gwna Beds, on the drive, about a quarter of a mile east of the house, which is traversed by zones of catamorphic shearing, is also traversed by another zone, wherein chlorites and white micas wind about epiclastic-looking grains, and this zone bears a strong resemblance to a Gwna Green Schist. There is a similar zone in a gneiss of the Gader Inlier [E 10639]. The pseudepiclasts, however, are cataclasts of the same albite as that of the undeformed portion of the slide. Now, the white micas and chlorites of this zone are undoubtedly authigenic, hence catamorphism is here transcended, and anamorphism, patently of dynamic origin, has set in. The degree to which it has developed is about the same as that of the Gwna Beds of the Llanfair-ynghornwy Belt, in which this gneiss occurs. In fact, we see here the dynam-anamorphism of the Bedded Succession in process of being superimposed upon the Gneisses, of the structures of which it is quite independent. It follows that the crystalline characters of the Gneisses are not an intensification of those of the Bedded Succession, but are their own.

Seven new pieces of evidence, therefore, go to confirm the view

[1] Fig. 94 ('G. of A.') will need to be modified, by insertion of a wedge of Fydlyn Beds between the gneiss and the Gwna Beds at the western infold.

that the crystallization and foliation of the Gneisses is older than the deposition of the Bedded Succession.

Note.—On the 1-inch map, the colour selected for the Gneisses has unfortunately, in process of printing, come out so as to be almost indistinguishable from that of the New Harbour Beds. The Gneiss of the larger tracts can be distinguished by its symbol, but on the smaller tracts there was no room for a symbol. Most of them can be identified from the Memoir. The tract at the word 'Mynachdy,' however, comes against New Harbour Beds at its north-western end; and there is a small one beyond it, between Gwna Beds and Serpentine. A distinctive colour-wash might, with advantage, be added to all the gneissic tracts by hand.

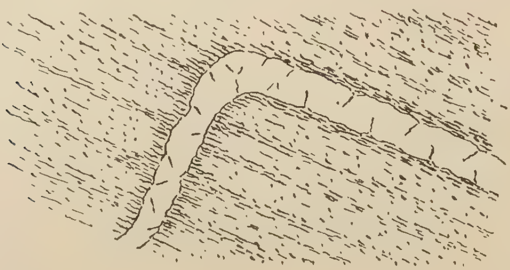
VI. The Origin of the Basic Gneisses.

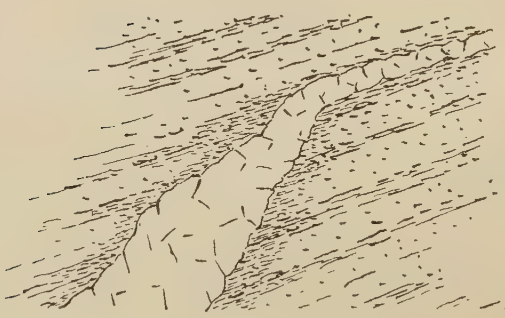
Some time ago I was led to suspect that the phenomena cited as evidence of movement after consolidation ('G. of A.' pp. 131–33, 903, 944) might not be conclusive; and that I might have overlooked signs of primary injection-banding, such as that of Skye, the Lizard, and Southern Australia. The development of gneisses has proved on re-examination to be essentially the same (p. 341), in the Middle as in the Aethwy Region.

Early stages.—The most primitive condition of the basic rock ('G. of A.' pp. 131–32, 322, 376, &c.) is an assemblage of closely-crowded masses, usually ovoid, but occasionally sub-cubic, or even exhibiting re-entering curves, of unfoliated or faintly-foliated dioritic matter, which (though occasionally) is not prevalently coarse. Evidently this is (as in the Lewisian complex and elsewhere) a product of early differentiation of the basic magma. Acid albitic matter acts as a matrix to basic lumps; but this matrix darkens in some directions, and then acts as matrix to acid masses. Further research is, therefore, needed to determine the general order of differentiation, which seems to be less simple than in the Lewisian complex; this, however, is not essential to our present purpose. In only a few yards (as at the Werthyr sections) the dioritic masses begin to be flattened, and the whole assemblage passes rapidly into a thorough banded gneiss. Except for the differences in the nature and behaviour of the matrix, the phenomenon resembles, almost exactly, that of pl. ix in the Geological Survey Memoir on the North-West Highlands, which might almost pass for an illustration of it. So far as the foregoing description goes, this process might have taken place before consolidation: that is, before crystallization of the differentiated magma. The more basic of the unfoliated masses, however, frequently contain groups of large quasi-porphyritic hornblendes. When flattening begins, these groups also flatten; and in the banded rock they acquire a foliation as well. Now, had the magma been fluid when the flattening took place, these groups would have disintegrated, and their crystals have been floated away one from

the other. It must, therefore, have possessed sufficient cohesion to hold the groups together, which could not have been the case until consolidation was very far advanced, or, possibly, complete. Further, in thoroughly-banded, and even folded, gneisses all over the Allor area, survivals of these peculiar hornblende-groups can usually be found on scrutiny. Such gneisses, therefore, must have been produced by the rolling-out of a differentiated magma, and at a very advanced stage of crystallization.

Fig. 4.—*Pegmatites with foliated ultrabasic encasements in basic gneisses: road-fork south-west of Clegir-mawr; and Craig-allor* ($\times 1\frac{1}{2}$).





Pegmatites.—Three generations of these have now been distinguished. It is with the first and second generations that we are concerned here. Most of them are composed almost wholly of albite, often beautifully twinned; but the wider veins contain hypidiomorphic hornblendes, occasionally measuring as much as an inch in diameter. Pegmatites with a width of 2 or 3 inches, however, are rare, the majority being less than half-an-inch, while many are no more than a quarter of an inch thick. Despite the fact that their crystals interlock with those of the gneiss, they do not pass gradually into it, but are defined in the sharpest manner, their margins being clear even under the microscope. By far the greater number of them conform to the foliation of the gneiss

(and this may be the case even where it is folded), thus greatly accentuating its already banded aspect. Some, however, truncate that banding and foliation at various angles (fig. 5); while sometimes a conformable seam will suddenly turn round, and cut across the gneissic banding at angles of 60° or even 90° (fig. 4). At the time of their formation, therefore, the gneiss, already very near to complete crystallization when rolled out, must have been solid. Now, it is a constant feature of these pegmatites that the gneiss in contact with them is much more basic than it is elsewhere, being

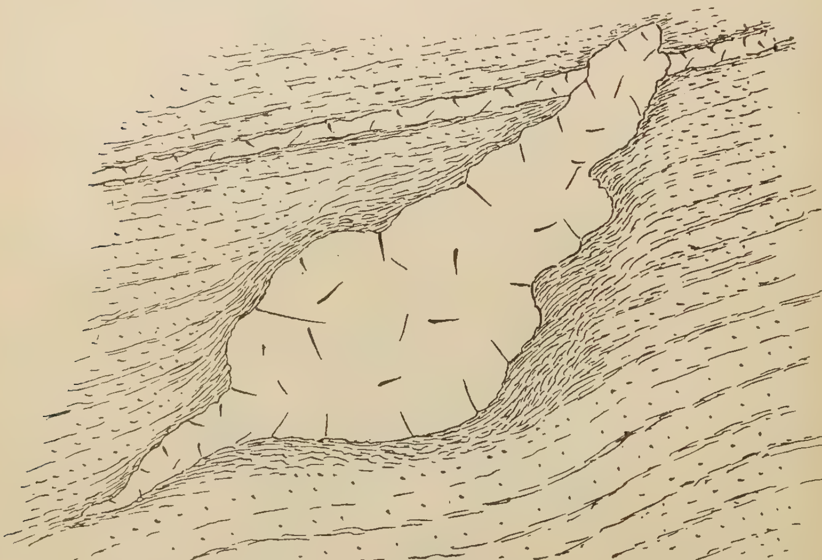
Fig. 5.—*Pegmatites with foliated ultrabasic encasements in basic gneiss: roadside south of 'P' of Pandy Treban* (× 5).

often composed almost entirely of hornblende, with a very little albite, and rather more ilmenite and sphene than usual. The hornblende is the same green aluminous variety as in the body of the rock. Each little pegmatitic seam, in fact, is enclosed within a pair of black skins or encasements of thicknesses ranging from $\frac{1}{8}$ to half-an-inch, thus accentuating still further the banded aspect of the gneiss. Moreover, where the acid seams turn round and cut across the banding, they are duly accompanied by their black encasements. From the respective thicknesses, it is estimated that a mean of the composition of pegmatite and selvage must be very nearly the average composition of the adjacent portions of the gneiss. It is, therefore, evident that this dark encasement is an ultrabasic residuum, left after the rock had been robbed of the elements of albite. These pegmatites, accordingly, cannot be

intrusions: they must be segregations,[1] and segregations from a solid rock. Two generations of them can be distinguished, as in fig. 6, where one is seen to cut the other, and both have ultrabasic encasements.

In connexion, however, with the origin of the gneissic structures, our principal concern is with the encasements, and the most interesting feature of these is that they are foliated. Where their parent pegmatites conform to the gneissic banding (as in the

Fig. 6.—*Pegmatites with foliated ultrabasic encasements in basic gneiss, showing deflected foliation: about 170 yards north-north-west of Craig-allor (natural size).*



right-hand part of fig. 4, p. 344), their foliation is parallel to their trend and to their own bounding-planes, as in that of the other bands of the adjacent gneiss. Even where gneiss, pegmatite, and encasement are all folded together, the foliation of the encasement is folded with the whole triple system, and remains conformable to

[1] The pegmatites of the third generation, although much larger, and quite as acid, have no dark encasements, but cut gneiss which has that feature. Moreover, these veins are not confined to the basic, they appear also in the acid gneisses which are probably of sedimentary origin. At the crag west of the road-fork west-south-west of Clegir-mawr, one of them cuts across the junction of the two. There are, consequently, grounds for suspecting them to be intrusions, at any rate in the positions where we now see them, although they may not have come from far away, or have emanated from any large batholite, for their felspars also are those of the hornblende-gneiss itself.

their bounding-planes. But where (as in the left-hand part of fig. 4) their parent pegmatites turn round so as to cut across the banding, then, although they accompany their pegmatites, their foliation does not turn round, but retains the same direction as before, and so it is now transverse to their trend and to their own bounding-surfaces. Moreover, where they accompany pegmatites of the somewhat irregular kind shown in fig. 5 (p. 345), the same is the case. In general, we are able to discern a law, which is that, whatever may be their own direction in relation to the gneissic structures, their foliation steadily conforms to that of the gneiss, with which it is, indeed, identical.

But we have seen that the gneiss had solidified before the segregation of the first generation of pegmatite. It follows that the foliation of the ultrabasic encasements must have developed within a solid rock.

By what agency was it developed? Let us consider, first, whether the new hornblendes are simply enlargements of pre-existing crystals that were already foliated, the direction of the vertical axes of which would determine the direction of growth. But there has also been an increase in the number of the crystals, and this implies that new ones must have grown in such a direction as to give rise to foliation. Can we then avoid looking to the now familiar agency of strain? The two questions which call for answer are, first, whether effects such as we see here can be produced by stresses operating within a solid rock; and, secondly, whether there be any evidence that such stresses were actually operating within these gneisses. To the first question, another part of this paper supplies, as it happens, a decided answer. For we have seen that in the hornblende-schists of the Penmynydd Zone there are ultrabasic encasements of similar origin, and that they are foliated. Now, in the Penmynydd Zone, there is no doubt whatever ('G. of A.' pp. 118–28) that the rocks were solid, and that the foliations are effects of dynamic metamorphism. To the second question, the phenomena now described supply an answer. In the first place, we have seen that the banding of the basic gneisses is clearly traceable to stresses, and that these were in operation at a stage when consolidation of the differentiated magma was, at any rate, very far advanced. These banded rocks are, on Craig-allor and other places, folded, and the first generation of pegmatites with encasements, which we know to have been posterior to consolidation, is folded with them. Nor is this due to the fact that they merely followed pre-existent folds, for the foliation of their encasements is also folded. Further, the folds are, in places, torn out into thrusts. Such rupture is, in itself, an evidence of solidity. But we also find that the gneiss is much more strongly foliated and 'spun-out' along the limbs (especially the middle limbs) of the folds than at their apices, and that foliation attains a maximum along the thrust-planes. Along one such thrust there is a quarter-inch seam of hornblende-schist with micas, and this seam is itself minutely folded. Here, then, we

have evidence, not merely of a foliation posterior to consolidation, and of its being a consequence of deformation, but also of true dynamic anamorphism, for a new mineral has appeared along a plane of maximum deformation, subsequent to which the foliation was itself re-folded. Certainly, in such sections as those of fig. 4 (p. 344), there cannot have been shearing stress with differential movement, for the pegmatite is not disrupted. But in other sections the pegmatites are seen to have been affected by the agency which induced the foliation, for they are penetrated, and sometimes crossed, by the foliated hornblendes of their encasements; besides which, where the encasements are sharply folded (as at Cefn-du in the Aethwy region) the pegmatites are sheared, and acquire a foliation of their own. Finally, there are cases (fig. 6, p. 346) where, around a pegmatite of the second generation, the foliation, both of its own encasement and of the adjacent gneiss, is markedly deflected; which could not have taken place until after the pegmatite (if, indeed, it were ever fluid) had thoroughly consolidated.[1] Yet the first pegmatitic generation, and still more the gneiss itself, had been solid rock long before the separation of this pegmatite. Our second question, accordingly, is answered. Stresses were operating within the basic gneiss, perhaps continuously, but certainly at intervals ranging from a late stage of the consolidation of the differentiated magma until after its complete consolidation, and continuing even after the separation of the second generation of pegmatite.

The evidence as to folial genesis in these gneisses may be summarized as follows:—In no case is it necessary to postulate movement anterior to consolidation. There are cases where foliation-structure might be anterior or posterior to consolidation. But, where definite evidence is available, it shows that folial structures have developed within solid rock, that stresses were in operation at that time, that in some cases at any rate the foliation must be ascribed to them, and that it was accompanied by mineral metamorphism.[2]

Posterior to consolidation, however, is not necessarily posterior to cooling. And there is decisive evidence that, in this case, the rocks were at a high temperature throughout; for there are no chilled selvages anywhere, not even to the third generation of pegmatites, which are very coarse. Now, it is well-known that the adaptability of crystals, both to pressure and to metamorphism,

[1] This deflection might be ascribed to the force exerted by crystalline growth in the pegmatite itself (a principle to which attention has been drawn by Dr. Alfred Harker). But, if so, such a deflection would be the rule around these pegmatites, which is not the case.

[2] That mineral metamorphism can rarely be demonstrated in these rocks is easily understood, if we reflect that their magma crystallized originally, not as dolerite or gabbro, but as diorite, not as a pyroxenic but as an amphibolic rock; and that amphiboles, being common products of dynamic metamorphism, would naturally be stable under such conditions.

is greatly facilitated by a high temperature; which may enable us to understand the apparent ease with which the ultrabasic selvages acquired a foliation.

VII. Chronology of the Gneisses.

Banding and permeation.—It has been assumed ('G. of A.' pp. 139–42) that permeation, granitoid gneiss, and gneissoid granite, being higher stages of granitization than banding, are also later stages. But re-examination of the section at Henblas ('G. of A.' pl. xv) has revealed that a good deal of the rock into which the bands were injected, lit par lit, though with transgression at acute angles ('G. of A.' fig. 21), was already a permeated biotite-gneiss. Banding is, therefore, in some cases at any rate, later than permeation. Yet, as the bands are still sodium-granites, the banding is to be regarded as a fresh invasion by the same magma, although the conditions did not at this stage bring about such intimate union as before.

The basic and the acid gneisses.—On re-examination of many sections in Allor and at Henblas, not a single case has been found where granitoid permeation in biotite-gneiss is later than any basic rock. The sillimanite-biotite-gneiss at Werthyr alluvium ('G. of A.' pp. 322–23; E 11378) is a lenticular xenolith 100 to 150 feet wide, within the hornblende-gneisses of Allor. No decisive junction has been found, but the two rocks are seen within 20 feet one of the other. The basic gneiss contains rather fewer pegmatitic seams than usual, and they have the characteristic ultrabasic selvages; foliation is often rude, and the aspect of the rock dioritic. So soon as we pass into the biotitic gneiss, granitoid permeation (which is really a sort of granitoid albitization) becomes intense. Had the basic gneiss existed when this permeation was going on, it could not have escaped. And it has escaped. The same relations are seen 170 yards away to the west, where, too, the strikes of the two gneisses diverge at an angle of 45°. Also, at the northern boss on the eastern side of the alluvium, and at the forking of the roads west-south-west of Clegir-mawr, the foliation of biotitic gneiss is truncated by unfoliated or feebly foliated basic rock. The whole body of evidence therefore compels me to abandon a view previously expressed ('G. of A.' p. 903), and enables us to escape from a perplexity created by that view ('G. of A.' p. 904). For it is now evident that the basic magma was introduced after the granitoid permeation had ceased. Yet, as the basic intrusions have no chilled selvages, the permeated rocks must have still maintained a high temperature.

The Gneissic Succession.—The foregoing evidence enables us to revise, and also considerably to extend, our scheme of the chronology of these ancient rocks, which may be summarized as

follows; although it must be remembered that stages represented as distinct may have overlapped in time:—

<table>
<tr><td>(13) Third generation of pegmatite (temperature still high).</td><td></td></tr>
<tr><td>(12) Second generation of pegmatite, with ultrabasic selvages.</td><td rowspan="3">Deformation, folding, and metamorphism.</td></tr>
<tr><td>(11) First generation of pegmatite (ultrabasic selvages).</td></tr>
<tr><td>(10) Production of gneissic banding ....</td></tr>
<tr><td>(9) Crystallization of magma (nearly or quite complete).</td><td></td></tr>
<tr><td>(8) Differentiation of magma.</td><td></td></tr>
<tr><td>(7) Intrusion of basic magma.</td><td></td></tr>
<tr><td>(6) Unknown interval (temperature high).</td><td></td></tr>
<tr><td>(5) Granitoid banding.</td><td></td></tr>
<tr><td>(4) Granitoid permeation.</td><td></td></tr>
<tr><td>(3) Granitoid intrusions and thermometamorphism.</td><td></td></tr>
<tr><td>(2) Disturbance and dynam-anamorphism.</td><td></td></tr>
<tr><td>(1) Sedimentary rocks.</td><td></td></tr>
</table>

Yet we do not know the end, and hardly anything of the beginning, of the gneissic process. For our knowledge of the first two stages indicated is little more than a glimpse into the mystery of these ancient rocks.

VIII. Recapitulation.

It may be well to summarize the principal contents of this paper:—

(1) The metamorphism of the Complex is older than the pyroclastic series of Bangor.

(2) The Fydlyn Beds have been identified at three places in the northern region, consequently the formation must be extensive. It lies at the base of the Bedded Succession, between the Gwna Beds and the Gneisses. Its relations add to the evidence for widespread inversion, and reveal major infolds hitherto unknown.

(3) The Penmynydd Zone. A small inlier shows the selective nature and rapid development of the metamorphism. Siliceous augen in a hornblende-schist rob that rock of acid matter.

(4) The view that the Gneisses are older than the Bedded Succession is confirmed.

(5) During the development of the basic gneisses, the separation of pegmatites robbed the rock of acid matter. Foliation was induced in solid rocks, and in some cases this can be assigned to strain.

(6) The parent-magma of the basic gneiss was introduced after the granitoid permeation of the acid gneisses. Recognition of this makes possible a revised and extended chronology of the most ancient member of the Mona Complex.

Discussion.

Sir Jethro Teall expressed his appreciation of the great work that the Author had done in Anglesey. In the speaker's opinion no part of the British Isles of equal area had been surveyed and described in greater detail, or with more accuracy. The present

paper added new facts of importance, some of which confirmed, while others were opposed to, conclusions at which the Author had arrived, and thus he appeared as the critic of his own work; certainly, no more competent critic could be found.

The Author said that attention had been called to the great amount of work, especially experimental work, which remained to be done before we could reach a satisfactory general view of the genesis of the crystalline schists. Might not good results be obtained by the use of crystallizable salts which are amenable to change under laboratory conditions? In the fascinating subject of the tectonics and metamorphism of these rocks, investigators must be prepared to abandon many an attractive theory, confident, however, that the sounder one which takes its place will prove yet more attractive and more stimulating.

15. *The* Glaciation *of* North-Eastern Ireland. By Major Arthur Richard Dwerryhouse, T.D., D.Sc., M.R.I.A., F.G.S. (Read June 28th, 1922.)

[Plates XXIII & XXIV.]

Contents.

I. Introduction.

The region to be described covers the counties of Antrim and Down, with parts of Armagh, Londonderry, Tyrone, Monaghan, and Louth, in all about 3200 square miles, and is included in sheets 6, 7, 8, 12, 13, 14, 18, 19, 20, 21, 26, 27, 28, 29, 34, 35, 36, 37, 47, 48, 49, 59, 60, 61, 70, and 71, of the maps of the Ordnance Survey of Ireland on the scale of 1 inch to the mile.

The area is also covered by Bartholomew's 'Quarter-inch to the mile map of Ireland', Sheet 2, which contains most of the place-names used in this paper.

References to the previous papers on the subject are collected in a 'Bibliography of Irish Glacial & Post-Glacial Geology' by R. Ll. Praeger, Proc. Belfast Nat. Field-Club, App. (1896), and in a Summary of Recent Glacial Investigations by the B.N.F.C., *ibid.* App. vii (1905–1906).

The area is naturally divided into four geographical units—the basaltic plateau of County Antrim, the Trias-filled valley of Belfast, the undulating Palæozoic area of Down and Monaghan, and the igneous areas of the Mourne Mountains, Slieve Croob, and Carlingford.

(1) The Basalt-Plateau.

The great plateau of County Antrim is formed of Tertiary basalts lying unconformably upon various older rocks, including Dalradian schists, Carboniferous, Triassic, Liassic, and Cretaceous rocks. The present surface of the basalt country forms a trough with its axis running north and south. The central valley is occupied by Lough Neagh, the waters of which stand at 52 feet above, and the lowest portion of its floor at 50 feet below, sea-

level, and by the lower course of the River Bann and the valley of the River Main. The eastern and western portions of the plateau rise into extensive uplands.

The western margin, extending from Magilligan Strand, at the mouth of Lough Foyle, to the western shores of Lough Neagh, forms in its northern part the bold escarpment of Binevena and Benbradagh, which overlooks the valley of the Roe and the towns of Limavaddy and Dungiven in the rolling country formed by the Dalradian schists and gneisses and the Carboniferous rocks which overlie them on the northern flank of the Sperrin Mountains.

Farther south, where the basalts come into contact with the great schistose mass of the Sperrins, the escarpment is not so marked, owing to the greater height of the land on the west. South of the general line of the Sperrins the level of the plateau falls towards the basin of Lough Neagh, and the escarpment, although still present, does not form a conspicuous feature of the landscape where it passes from the neighbourhood of Magherafelt to Moneymore, and onwards in the direction of Coalisland.

The eastern escarpment of the plateau runs along the sea-coast from Benmore (Fair Head) on the north, to the head of Belfast Lough, and thence by Cave Hill, Black Mountain, and Colin to the neighbourhood of Hamiltonsbawn in County Armagh. South of this point the basalt is represented by outliers at Markethill and Poyntzpass, but these do not form marked features.

The country inland from the eastern cliffs is very hilly, and culminates in the rounded dome of Trostan (1817 feet O.D.), while farther south the peaks of Sliemish (1437 feet) and Divis (1567 feet) form the dominant elevations.

The eastern escarpment has been deeply scored by streams which flow down its steep face into the North Channel, giving rise to the famous Glens of Antrim. These, in succession from the north, are Glen Dun, Glen Aan, Glenballyemon, Glenariff, Carnlough Glen, Glenarm, the valley of the Larne Water, and the smaller glens along the face of the Belfast Hills.

In the extreme north-east of the area, in the neighbourhood of Ballycastle, the basalts with the underlying Chalk and Trias have been removed by denudation, laying bare the Dalradian schists and gneisses below; but there are several outliers indicating the former extension of the basalts over the whole area. Chief among these northern outliers is the great dome of Knocklayde, which forms the most conspicuous feature in the Ballycastle district, and is separated from the main mass of the plateau by a deep valley that played an important part in the drainage of the country during the Glacial Period.

East and west respectively of Knocklayde lie the valleys of Glenshesk and of the River Tow, the latter being the pre-Glacial outlet of the Bush River.

The central low-lying portion of the basalt-plateau is occupied by the valley of the Bann, and by that of the almost parallel stream, the River Main. The Bann leaves the northern end of Lough Neagh

at Toome Bridge, flowing through Lough Beg and thence northwards to the sea near Port Stewart; while the River Main rises in the northern part of the central valley, flows southwards, and, after receiving several tributaries from the eastern hills, enters the northern end of Lough Neagh at Randalstown.

There is thus presented the unusual phenomenon of two parallel streams flowing through the same depression in opposite directions. In the latitude of Portglenone the streams approach within 5 miles of each other, and in no case is the watershed between them more than 300 feet above the bed of the Main, or more than 600 feet above that of the Bann.

(2) The Belfast Valley.

This valley with its seaward extension, Belfast Lough, lies between the basalt escarpment on the one hand and the Silurian uplands on the other. It is floored by deposits of Triassic age which are much softer than the surrounding rocks, and it is doubtless owing to this difference that the valley owes its existence.

It is the valley of the lower part of the River Lagan and of a smaller parallel stream, the Blackstaff, both of which flow over Glacial deposits, but cut in places into the underlying Trias.

The Upper Bann passes across the head of this valley on its way to Lough Neagh, and is separated from the Lagan by an alluvial plain, the deposits of which rest upon Glacial drift of considerable thickness. Pending further investigation of the form of the rock-head below the drift, the pre-Glacial drainage of this area is a matter of conjecture.

(3) The Palæozoic Country of County Down.

This country is undulating and in many places hummocky. It rises to over 700 feet in its northern part, which is separated from the southern part by a narrow Trias-filled valley (under 200 feet) that runs eastwards from Belfast by way of Comber to the head of Strangford Lough.

The southern part rises to some 600 feet near Saintfield, and falls away gradually towards the south with many minor hills, both of drift and of solid rock, diversifying its surface. These minor hills, drumlins, and *roches moutonnées* give to the county its characteristic hummocky surface, which, locally, is likened to a basket of eggs.

(4) The Igneous Areas of Mourne, Slieve Croob, and Carlingford.

The Silurian rocks of the southern part of County Down are invaded by two masses of granite, the older and northernmost occupying a belt of country which stretches some 6 miles from north to south, and extends from Castlewellan on the east to Newry and thence to the neighbourhood of Camlough in County

Armagh. In Armagh the granite becomes associated with other igneous rocks of a more basic type, and forms the complex of Slieve Gullion (1895 feet O.D.) and Carlingford Mountain (1935 feet).

The Mourne Mountains also consist of granite, and form an isolated mass culminating in Slieve Donard (2796 feet): there are, moreover, several other peaks rising to more than 2000 feet above the sea.

The high land of the Newry-Castlewellan area and the Mourne Mountains on the one hand, and the Slieve Gullion-Carlingford mass on the other, are separated by the great valley of Poyntzpass and Carlingford Lough, to which reference will be made later.

II. The Northern Part of the Antrim Plateau (see map, fig. 1, p. 356).

[1-inch Ordnance Map, Sheets 7 & 8, & parts of Sheets 13, 14.]

Throughout almost the whole length of the coastline the country is bounded by high, nearly perpendicular cliffs, the exceptions occurring in Ballycastle Bay, at the mouth of the Carey River, near Bushmills at that of the Bush River, in the neighbourhood of Portrush, and at the mouth of the Bann.

A fault running near the line of the railway from Armoy to Ballycastle divides the district into two regions of notably different relief. The eastern portion extending from Torr Head and Fair Head to Ballycastle and Armoy is a country of marked physical relief, and is drained by the Carey River (with its tributary the Glenmakeeran River) and by the Glenshesk River, the waters of which enter the sea at Ballycastle.

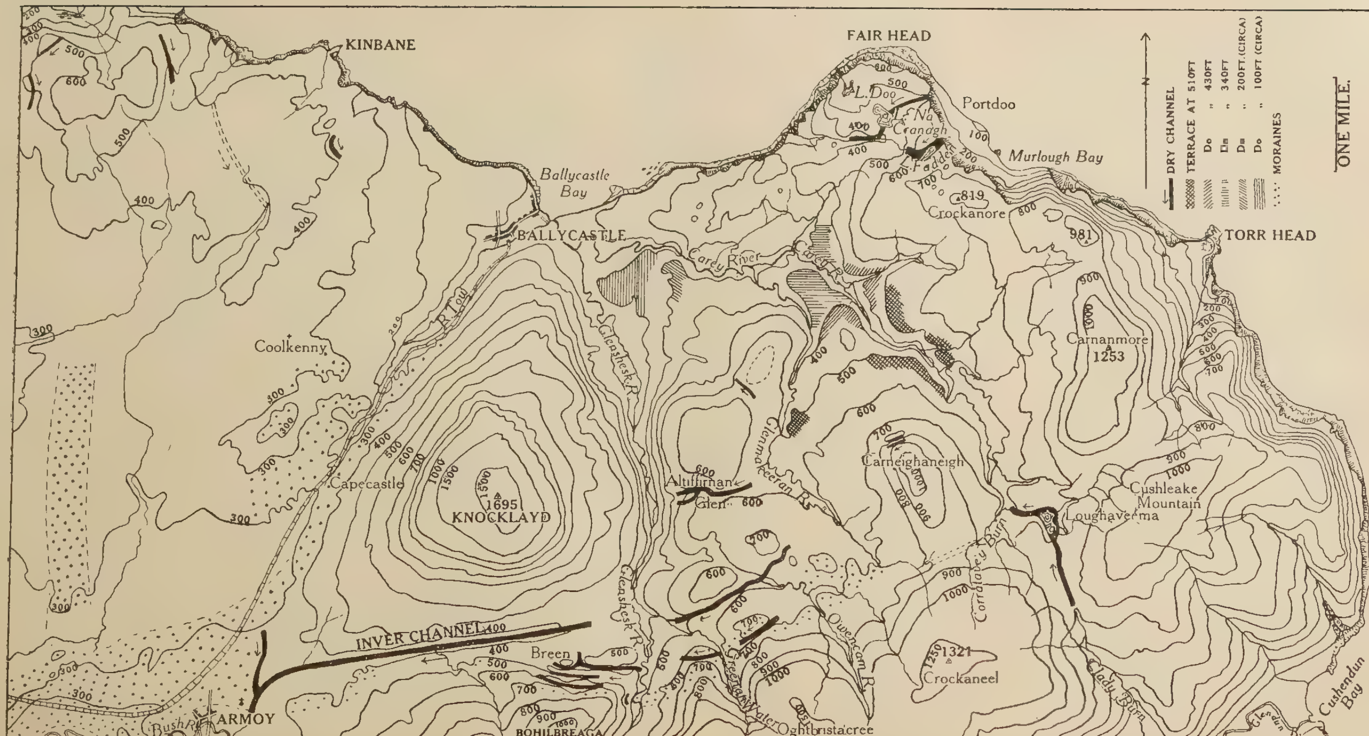
The Carey River may be said to take its rise on Cushleake Mountain, although the drainage from the slopes of this upland flows first into Loughaveema, and thence underground for some distance before joining the other tributaries. The valley of the Carey River is deeply cut through Glacial clays and gravels, although there is but a thin covering of these deposits on the higher ground of Carnanmore and Carneighaneigh which form its flanks.

At a point at an altitude of 606 feet on the main road, on the left bank of the stream, there is a thin covering of drift containing, among other erratics, the coarse-grained dolerite of Fair Head; Carboniferous sandstone probably derived from the lower part of the cliffs above Portdoo, east of Fair Head; red quartzite; basalt; and local schist; also large pieces of vein-quartz showing striations.

At a point 100 yards above Corratavey Bridge, in the bed of the Corratavey Burn, is a section of a reddish-brown boulder-clay with a covering of gravel. The boulder-clay contains schist, flint, chalk, basalt, gneiss, vein-quartz, and big boulders of red quartz-porphyry derived from the country immediately to the east.

Boulder-clay similar in composition to the last also occurs at intervals over the country lying between the valley of the Carey River and Fair Head.

Fig. 1.



[The thick black bands in this and subsequent figures indicate the course of dry Glacial overflow-channels.]

The valley of the Glenmakeeran River is, in its upper part, wider and more open than that of the Carey, and is encumbered with drift up to a height of about 680 feet. This drift is gravelly in character, and the level of its upper edge is remarkably constant. Above that level the drift is scanty, but there are numerous scattered boulders of Fair Head dolerite and Carboniferous sandstone.

In the lower parts of these valleys the Glacial gravels are strongly in evidence, in places reaching over 100 feet in thickness, and they are arranged in a series of terraces through which the streams have cut, leaving against the hillsides flat-topped shelves which make very conspicuous features in the scenery.

The terraces stand at 680, 510, 430, and 340 feet, while indistinct remnants of other terraces at still lower levels appear in the angle between the Carey and Glenshesk Rivers near their junction (see fig. 1). The uppermost terrace was seen only in Glenmakeeran, and is not so well marked as those at lower altitudes.

Beneath the terrace-gravels a red boulder-clay is observed in several sections, and in one of these it is 20 feet deep, its base not being exposed.

The terrace-gravels contain Carboniferous sandstone, basalt, schist, chalk, flint, vein-quartz, red granite, red quartz-porphyry, and the riebeckite-eurite of Ailsa Craig, also the granite of Goatfell and the columnar quartz-porphyry of Drummadoon in Arran.

On the summit of Fair Head there is a little drift, but many surfaces of dolerite are strongly moutonné and striated, and erratics of granite including that of Goatfell are sparsely scattered over the undulating surface. The striæ on the shores of Lough Doo run from north 40° east (true).

In Murlough Bay, south-east of Fair Head, so many large landslips have taken place since the formation of the drifts that it is impossible to make out the sequence of the Glacial deposits, although boulder-clay can be seen in several places.

The surface of the Carboniferous rocks which lie between Fair Head and Ballycastle is covered by gravelly drift in places showing moraine-like forms; but the denudation here has been severe and what look, at first sight, like moraine mounds may be the remains of a former extension of the gravel-terraces.

The flanks of Knocklayde are but sparsely covered with drift, except on their lower slopes, where gravels similar to those already described occur, although, owing to the steeper inclination of the sides of Glenshesk, no terraces can be detected in that valley.

The western part of the area, that west of the Ballycastle Railway and the fault, is less heavily covered with drift, except in the morainic area extending from Armoy to Ballymoney, which will be described later.

The coastal region consists of rugged basaltic uplands with but little drift, and inland between these uplands and the morainic country lies a large bog drained by the Inver Burn, Stracam River, and other streams into the Bush River.

The drift over the whole of this region is characterized by the presence of the rock of Ailsa Craig and other northern erratics.

The Moraines.

In the southern portion of the area is an enormous accumulation of morainic material, for the greater part arranged in long ridges.

Crossing the country from east to west, these ridges first become conspicuous on the northern flanks of Crockaneel and Oghtbristacree, between the Owencam River and the Greenan Water, whence they extend in a south-westerly direction to the Glenshesk River, which they cross at a point about 500 feet above the sea.

West of Glenshesk the moraine is continued along the slopes of Bohilbreaga, above a strongly-marked series of overflow-channels, to be described later.

The valley between Bohilbreaga and Croaghan on the south, and Knocklayde on the north, shows numerous mounds of drift which mark the continuation of the moraine; but it is not until the western end of the valley is reached, near the church and ancient round tower of Armoy, that it again becomes a marked feature.

From Armoy westwards by Gracehill, Stranocum, and Culramoney to Ballymoney the moraine forms a prominent ridge or series of ridges standing 100 feet above the plain on the north, and deflecting many northward-flowing streams to the west. Thus the Bush River, which flows into Armoy from the south, on reaching the southern flank of the moraine turns abruptly westwards, as do also the Flesk Water and several smaller tributaries. The river eventually breaks through the barrier at Stranocum.

Farther west, the Breckagh Burn, Glenlough River, and Ballymoney River are similarly deflected, in this case into the Bann.

At Ballymoney the moraine turns northwards, and runs along the ridge of high ground that separates the lower portion of the valley of the Bush from that of the Bann.

The great moraine is the outermost and largest of a series of frontal moraines, and probably represents the terminal moraine of an ice-lobe which penetrated thus far during a re-advance of the Scottish ice at a late stage of the glaciation.

North of this Armoy-Ballymoney moraine are several other ridges, smaller and not so clearly defined. Thus, a mile east of Dervock is a ridge of gravel covered by contorted sands, with a thin layer of boulder-clay on the top. The gravels contain basalt, flint, chalk, vein-quartz, schist, quartzite, and an abundance of Ailsa Craig eurite. This ridge appears to be continued north of the Stracam River by the drift-mounds with similar contents which occur near Toberdoney Cross Roads, on the road from Dervock to Liscolman.

Another ridge runs from Doughery Bridge, 2 miles north-west of Armoy, northward to Kilmahamogue, while a further accumulation occurs along the railway from Capecastle to within a mile of Ballycastle, and extends across the valley westwards to Coolkenny.

There are several extensive ballast-pits along this section of the

railway, and in the largest of these the following section is to be seen:—

	Thickness in feet.
Brown sands with lines of pebbles	5
Coarse gravel containing boulders which measure up to 3 feet in length, with lenticles of red stratified clay......	20

Pebbles of Ailsa Craig eurite are very common in the gravel, which also contains masses of Carboniferous sandstone (Ganister) as much as 3 feet long, schist, gneiss, red quartz-porphyry, flint, chalk, quartzite, quartz-breccia, red granite, and basalt.

The whole drainage-basin of the River Tow (Ballycastle River), from Capecastle downwards, is deeply filled with drift, the streams flowing in deep valleys excavated in and floored by it. There is also deep drift all the way from Capecastle to Armoy, and there seems to be little doubt that, if the glacial deposits were removed, the Bush River would flow down the valley to the west of the railway, and enter the sea at Ballycastle, as it probably did in pre-Glacial times.

Glacial Overflow-Channels and the Origin of the Terrace-Gravels.

The terrace-gravels of the Carey and Glenmakeeran Rivers were formed as deltas in a temporary lake, the waters of which were held up by the ice-front; and the various terraces represent the successive levels of its waters as the margin of the ice slowly retreated northwards.

During the maximum extension of the Scottish ice, the whole of the ridge Cushleake Mountain–Crockaneel–Oghtbristacree–Agangarrive Hill, separating the area under consideration from Glendun which lies on the south, was completely overridden, and attention is now directed to the successive stages of its emergence from its ice-covering.

It will be evident, from the drainage phenomena which will shortly be described, that immediately after the masses of ice north and south of this ridge had ceased to be confluent, the glacier on the south (in Glen Dun) stood at a higher level than that in the Carey River and Glenshesk. This can be accounted for by the fact that the mouth of Glendun opening to the sea at Cushendun lay centrally in the track of the great ice-sheet issuing from the Firth of Clyde, and there was little to hinder its advance up the glen; while the Carey and Glenshesk area lay somewhat to the right of the centre of flow, and was protected to a certain extent by the great rampart of Fair Head, there being also a comparatively easy escape for the Clyde ice across Rathlin Island and through the channel between that island and Islay.

Accordingly, we find that there are two overflow-channels, both falling northwards, and connecting Glendun with the valleys lying in that direction. The smaller of these channels is at a height of slightly over 1000 feet, passes between Agangarrive Hill

and Orra More, cuts the watershed, and connects the head of a feeder of the Owenaglush River, a tributary of the Glendun River, with the head of Glenshesk (fig. 3, p. 365).

When this Owenaglush channel was operative, the ice on the northern face still stood at about 1000 feet, impounding a lake in the head of Glenshesk, and the waters of this lake overflowed the col between Croaghan and Orra More. The present level of this col is 950 feet; but there is a thickness of at least 30 feet of peat on the watershed, as can be seen in open section. There is a well-marked channel through the watershed, and the existing stream, the Shelton Burn, is diminutive when compared with the size of the valley in which it flows.

Another and much larger channel connects Glendun with the valley of the Carey River. The watershed, or intake, of this channel, which runs along the line of the main road from Cushendun to Ballycastle, is at a level of 840 feet. Loughaveema, the vanishing lake, lies in the channel (Pl. XXIII).

The Loughaveema channel was probably operative to some extent while the Owenaglush channel was still active; but at this stage it could only have carried the drainage from the ice, or, perhaps the overflow of a small lake held up in the head of the valley of the Clady Burn. As the ice-front receded, however, a much larger volume of water was diverted to this course. The channel is cut through the Dalradian schists, and is broad, deep, and streamless.

The records of the further stages of the first retreat of the Scottish ice have been obliterated by the subsequent re-advance, and it is in connexion with the great morainic system already described that we can again take up the chain of events.

When the ice stood at the level of the outermost ridge of the moraine the only lake of any importance impounded by it was that in the head of Glenshesk, which still overflowed by the Shelton Channel.

The floor of this part of Glenshesk is occupied by roughly stratified gravels consisting, for the greater part, of schist-pebbles, and this material appears to have been washed in through the Owenaglush Channel by way of the Altahullin Burn.

The moraine crosses the Glenshesk River at Coskemnacally, at about 500 feet above sea-level; the river has been deflected by it, and passes round its western end through a gorge cut in the Dalradian schists.

With a slight retreat of the ice a small channel ('lateral escape' type) was opened on the line of the road above Coskemnacally, at a height of 540 feet, and there are indications of a gravel-terrace or delta at about this level in the upper part of the valley. On the opening of this channel the Shelton Channel became inoperative, and the drainage henceforth was by way of the great valley between Knocklayde and Croaghan.

The next stage is marked by the cutting of a great series of overflow-channels on the northern flank of Bohilbreaga (see fig. 1, p. 356). At this period the ice-front stood against the northern

slopes of Carnanmore and Carneighaneigh at levels of about 1000 and 900 feet respectively, and a lobe penetrated the Glenmakeeran valley, covered the flanks of Crockaneel and Oghtbristacree to a height of between 700 and 800 feet, and filled Glenshesk up to the great Coskemnacally moraine. The lake in the valley of the Corratavey Burn, which was still receiving the waters from the Loughaveema Channel, overflowed by a deep (now peat-filled) channel between Carneighaneigh and Crockaneel, and thence along the edge of the ice, cutting the channel at 700 feet between the Owencam River and the Greenan Water, also that at a slightly lower level joining the valley of the latter stream with Glenshesk, and finally those above the village of Breen on the flank of Bohilbreaga.

The Breen channels form one of the most striking groups in the North of Ireland. There are three main channels and several smaller ones, all falling westwards, and eventually opening into the great Inver channel. The two largest of the Breen Channels are each about half a mile long, and from a study of the whole group on the ground it is possible to demonstrate the retreat of the ice stage by stage, indeed almost foot by foot.

A further retreat diverted the overflow of the Corratavey Lake to the northern face of Carneighaneigh, and two parallel channels were cut immediately above the site of the Glenmakeeran Shooting Lodge at 850 and 800 feet respectively; a channel also was opened from the headwaters of the Glenmakeeran River, at this stage occupied by a lake, through a col at a height of 689 feet (present level of the surface of peat). This channel flowed in a south-westerly direction, cut across the valley of the Owencam River, which stream it permanently captured, the old V-shaped channel leading over into Killuca Burn being still visible at a height of 30 feet above the present level of the Owencam River, at the point where it enters the gorge of the overflow (see fig. 2, p. 362). The gorge is cut in the schists and, at its lower end, in red boulder-clay containing northern erratics.

This Owencam channel opened into the valley of the Greenan Water, then an arm of the Glenshesk Lake, which at this stage stood at a level of slightly over 400 feet, and overflowed by the Inver channel, which it continued to do until finally drained by the removal of the ice from its lower end.

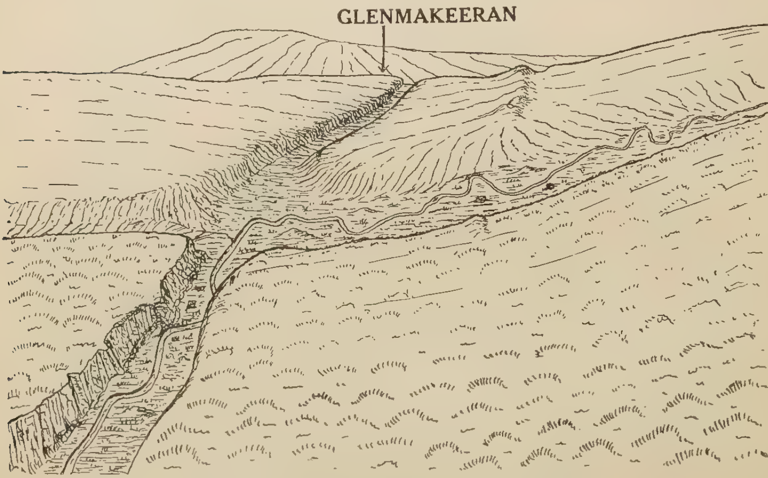
A further retreat rendered the Corratavey and Glenmakeeran lakes confluent round the northern end of Carneiganeigh, and allowed their waters to overflow the col (600 feet) at the head of what is now known as Altiffirnan Glen (see Pl. XXIV). This glen is an enormous dry gorge, excavated in hard schists to a depth of more than 100 feet. It winds considerably, and, at present, so small is the amount of drainage that an artificial channel 1 foot wide is sufficient to carry it off; even this is dry in summer.

At its lower end, where it enters Glenshesk, it divides into two portions, and of these the southern branch is the older, while the northern (which is also the larger and deeper) at present carries the

drainage. This bifurcation of the channel indicates that a lobe of ice still penetrated Glenshesk as far as this point, and stood at a level of about 500 feet, thus closing the outlet of the pre-existing northern valley, and allowing the waters to cut the southern channel. A slight retreat then opened the northern branch, which was rapidly deepened and widened by the powerful stream from Glenmakeeran Lake.

The Altiffirnan gorge comes to an end abruptly on entering Glenshesk, and is continued by a normal V-shaped valley comparable in magnitude with the existing stream. The change in character of the valley takes place at a level slightly above 400 feet, which has already been indicated as that of Glenshesk Lake and

Fig. 2.—*Capture of the Owencam River by an overflow-channel from the lake in Glenmakeeran.*



[The deserted valley is seen on the left, and Carneighaneigh in the background.]

of its great overflow the Inver channel. The cutting power of the Altiffirnan stream was neutralized so soon as it entered the waters of the lake, and the gorge ends abruptly at that level. The small V-shaped continuation is the work of the existing post-Glacial stream, which enters the gorge from the north just above the bifurcation.

The upper terrace in the Glenmakeeran valley can be correlated with the level of the intake of the Owencam channel, and the largest of the terraces in the Corratavey and Glenmakeeran valleys with that of Altiffirnan Glen.

A still further retreat opened a channel in the Townland of Glish, across the spur between the valleys of Glenmakeeran and

Glenshesk. This channel is much smaller than those on the south. The present level of its intake is 590 feet; but there is a thickness of at least 20 feet of peat above the solid rock, and the upper part of the valley is occupied by a long, narrow, swampy lake.

At or about this stage, the Scottish ice was no longer able to surmount the rampart of Fair Head and the cliffs above Murlough Bay and Torr Head; but the drainage from the ice, which stood level with, or slightly above, the summit of the cliffs, still found its way into the lake which occupied the head of the Carey River, and cut several channels through the Fair Head dolerites. The northernmost of these runs from the summit of the cliff, above the colliery at Portdoo, into Lough Na Cranagh, and another through Lough Fadden.

West of Ballycastle are several well-marked channels which drained small lakes held up by the ice in the basin-shaped valleys opening on to the line of sea-cliffs. These channels conveyed the water southwards on to the area of the bog, which lies between the basaltic uplands along the coast and the great Armoy moraine. Thus the waters of a temporary lake in Glenstaghey drained by a channel crossing the bog west and south of Carnsaggart, and those of the area around Ballintoy by way of the valley on the line of the road which leads southwards from Ballintoy School, the watershed in this case being at about 450 feet.

Finally, at the western end of the valley above Dunseverick there is a very big dry channel, cutting through the watershed from Lisnagunogue to the terminus of the electric railway at the Giant's Causeway.

The accumulated waters from the area between the uplands and the moraine found their way to the sea through a gorge-like valley now occupied by the Bush River. This valley, from the point where the river cuts the 100-foot contour to the town of Bushmills, has steep sides and a flat floor, and the present stream has little cutting power owing to its low gradient. This part of the valley is cut in basalt, and in several places: for example, at The Island, where the valley is over 50 feet deep and quite narrow, cliffs overhang the stream. Although the valley still carries the waters of the Bush River, a not insignificant stream, from its size and contour I should judge that it had required a much more powerful agent for its erosion.

From Bushmills to Portrush the cliffs are high and rugged, and I could find no features of glacial interest upon them.

The low-lying tract extending from Portrush to the River Bann consists largely of glacial accumulations and wind-blown sand, and, when that river is crossed, the basaltic slopes are found to be covered with glacial deposits, both gravel and boulder-clay, which yield strong evidence of their northern origin. Thus, at the brickworks south of Irish Houses, there is a section 15 feet deep in brown boulder-clay, containing big boulders of basalt, Carboniferous Limestone (striated) and chalk, and smaller masses of quartzite,

grit, flint, red Carboniferous sandstone, gneiss, and Ailsa-Craig eurite. This is at the southern end of the pit, and the boulder-clay forms a ridge north of which the brick-clays (laminated and without stones) were accumulated in still water.

About half a mile away to the north, at Drummaquill, Mr. F. W. Egan [1] mentions the occurrence of gravels containing large numbers of Liassic fossils, including *Gryphæa* and belemnites. On visiting Drummaquill I found that the gravel-pits are not now so extensively worked as formerly; but I was able to obtain numerous specimens of *Gryphæa arcuata*, several fragments of *Hildoceras bifrons*, some Liassic belemnites, as also a specimen of *Belemnitella mucronata* from the Chalk.

The Liassic débris can only have been derived from the neighbourhood of Portrush on the north, and this northern origin is borne out by the large masses of chalk and the pebbles of Ailsa Craig eurite in the boulder-clay south of Irish Houses.

The westernmost part of the coast entering into the area under consideration is that which extends from Castlerock at the mouth of the Bann to Magilligan Strand at the mouth of Lough Foyle. The coastline consists of precipitous cliffs of basalt, with a narrow strip of raised beach running along their foot and carrying the road and railway.

III. The East Coast of County Antrim.

The eastern coastal section of County Antrim will be most conveniently described in two portions—the first extending southwards from the region just discussed to the ridge of high land running from Garron Point south-westwards to Elginney Hill, north-east of Ballymena, and culminating in Colin Top (1426 feet); the second from that ridge southwards to the line of railway from Antrim on Lough Neagh to Greenisland on Belfast Lough.

The Northern Area (see map, fig. 3, p. 365).

A considerable part of the area is above the 1000-foot contour, and this elevated region is deeply trenched by a number of valleys falling eastwards to the sea-coast. These, in succession from the north, are Glendun, Glenaan, Glenballyemon, and Glenariff. There are also the western valleys of the Bush River and Glenravel, the latter carrying the light railway from Parkmore to Ballymena.

The ridge from Agangarrive (1225 feet O.D.) to Crockaneel (1321 feet) lying north of Glendun, and that from Crocknacreeva (1092 feet) to Gruig Top (1123 feet), separating Glendun from Glenaan, consist of the Dalradian schists.

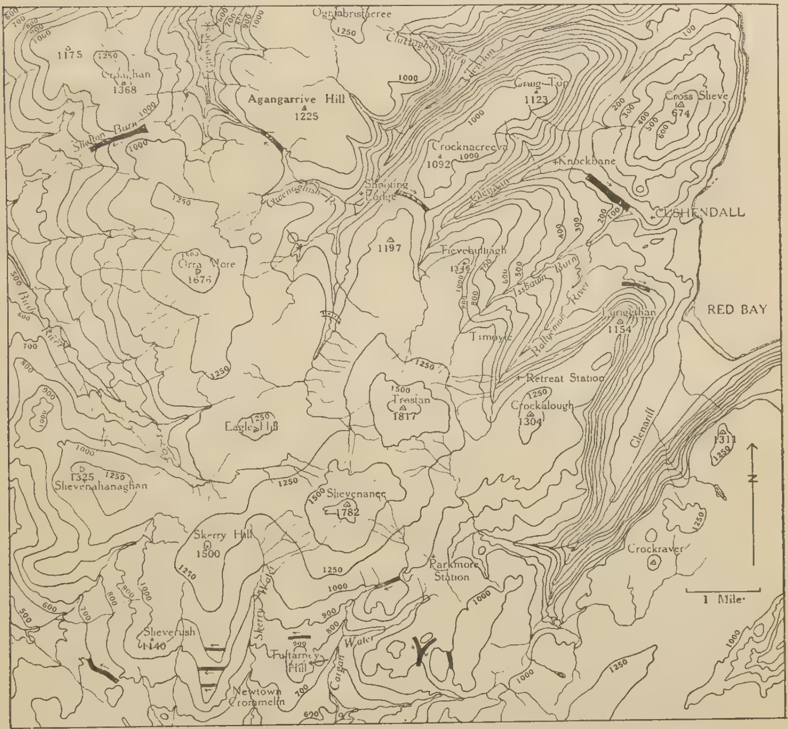
Cross Slieve, the isolated hill lying on the coast between Cushendun and Cushendall, is of Old Red Sandstone, with conspicuous beds of conglomerate, a small intrusion of dolerite near Cushendun, and a volcanic neck (Tieveragh) at its southern end.

[1] Mem. Geol. Surv. Ireland, Sheet 13, 1884.

With these exceptions, all the high land consists of the Tertiary basalts, which rest in some places directly upon the Dalradian schists, but elsewhere are separated from them by attenuated representatives of the Trias, Lower Lias, and Cretaceous rocks.

Glendun.—The greater part of Glendun, from the Shooting Lodge downwards, contains large quantities of gravelly drift, although in places boulder-clay occurs. In the stream immediately

Fig. 3.



below the Shooting Lodge the gravels and sands are fine-grained and stratified, and they contain abundantly schist and vein-quartz with a little flint, chalk, and basalt. All these rocks could be derived from the north-east.

The gravelly drift is, for the greater part, confined to the bottom and the lower slopes of the valley; while the higher slopes, from the 1000-foot contour downwards, are strewn with enormous numbers of big boulders of the local schist and gneiss.

Near the junction of Clyttaghan Burn with the Glendun River, and in the upper part of the valley of the burn, are considerable

morainic accumulations, consisting of sand and gravel with contents similar to those found near the Shooting Lodge.

The stratified deposits in the upper part of the valley were accumulated in a lake, which overflowed at a level of about 950 feet into Glenaan by way of a channel between Crocknacreeva (1092 feet) and Aghan (1197 feet).

Below the junction of Clyttaghan Burn there is a continuation of the gravelly deposits, which are again confined to the lower slopes. These extend down to the 50-foot contour below the viaduct, where they are replaced by another series which forms a dissected terrace at about 25 feet above sea-level, and is described on the maps of the Geological Survey as 'Raised Beach.' There is an extremely good section in this deposit immediately above the bridge over the river at Cushendun. A bend of the Glendun River is at present cutting into the terrace. The section is 30 feet high, and the base of the deposits passes below the level of the stream, which at this point is tidal. The gravels are strongly current-bedded, and contain layers of red laminated clay. The pebbles include quartzite, sandstone (Old Red), schist, flint, purple porphyrite, vein-quartz, also a granite with pink porphyritic felspars, which occurs *in situ* at the elbow of the road a mile north-west of Cushendun.

At the base of the gravels, at about high-water level, is a bed of silt containing fragments of wood and some roots, probably of a species of willow, the position of which suggests that they are in their place of growth; also hazel-nuts, a vertebra (probably of *Sus scrofa*), and some marine shells, including *Cardium edule* and *Littorina littorea*. The silt appears to rest upon the boulder-clay; but this part of the section, being below tide-level, is difficult of access.

The portion of Glendun which lies above the Shooting Lodge is of particular interest, as it contains evidence of glaciation by local ice which (with that at Newtown Crommelin shortly to be described) is the only indication that I have found in this part of Antrim. About 2 miles above the Shooting Lodge, at a height of 950 feet, a small, but distinct, terminal moraine crosses the stream with its convex face down stream, consisting entirely of basalt-boulders and basaltic detritus. It is evidently the product of a glacier emanating from a snowfield in the great basin which lies between Bush Head and Pollan Bridge, in the triangle between Trostan (1817 feet), Slievenanee (1782 feet), and Eagle Hill.

The long spur which runs from Gruig Top towards Cushendun is covered by great numbers of enormous boulders of the local schist.

Glenaan.—Glenaan shows no sign of the local glaciation, the Scottish drift being plentiful up to 1200 feet O.D. Above this level the country is deeply covered with peat, and all else is obscured.

An examination of the drift from about 700 feet upwards reveals

some interesting points. At 700 feet the stream is cutting in schist, and there is little else in the drift; but, slightly farther up stream, there is an outcrop of the Chalk followed by that of the Tertiary basalt, and both these rocks become plentiful in the drift so soon as their respective outcrops have been passed. Schist is still present in great quantity and in very large masses, although we are now above its outcrop, both physically and stratigraphically. This shows conclusively that the movement of the ice was up-stream, an inference which is confirmed by numerous other observations.

On the low flat col between the head of the Glenaan River and that of the Issbawn Burn is an extensive 'floating bog', and in the latter stream (at an elevation of 1050 feet) gravelly drift occurs, containing much schist and a boulder of purple porphyrite (the nearest outcrop of which is at Knockans, some $2\frac{1}{2}$ miles away to the north-east, and at a much lower level: namely, 300 feet above sea-level).

About a quarter of a mile farther east, on the northern flank of Timoyle, at an elevation of 900 feet, is an extensive deposit of red sandy drift, consisting largely of Triassic débris and resting upon basalt. It contains boulders of schist and vein-quartz, as well as pebbles of quartzite from the Old Red Sandstone conglomerates of Cross Slieve.

The spur which separates the valley of the Issbawn Burn from Glenaan has its highest point in Tievebulliagh (1346 feet), of which the northern face, consisting of basalt, falls almost vertically for 400 feet. On the summit of this escarpment of Tertiary basalt are numerous boulders of Dalradian schist, showing that Tievebulliagh was entirely overridden by the ice from the north.

Glenballyemon.—In Glenballyemon are many sections in Glacial deposits. Below Ballyfad, at 300 feet, the river cuts through some 20 feet of bright-red boulder-clay, with lenticular beds of red sand. The boulder-clay contains basalt, chalk, flint, quartzite, vein-quartz, Old Red Sandstone, Cushendun quartz-porphyry, and schist, the boulders being nearly all striated. For a distance of nearly three-quarters of a mile, up to a level of 400 feet, the river-channel is in this boulder-clay, and a similar deposit is exposed at intervals in both the river and its tributaries up to 600 feet.

Boulder-clay is also exposed in a small basalt-quarry on the side of the main road opposite Retreat Station, on the Ballymena & Cushendall Railway, at about 850 feet above O.D. Here a tongue of the boulder-clay lies beneath a mass of basalt which has the appearance of being in place, for, so far as can be seen, it is continuous with the flows on the slope above the quarry. The nether surface of the basalt mass, exposed during the quarrying operations, was seen to be striated from north-east to south-west. The tongue of boulder-clay appears as if it had been forced into the plane between the successive flows of basalt from the scarp-face at the northern end of the quarry.

The boulder-clay contains numerous pebbles of quartzite derived from the Old Red Sandstone conglomerates, also basalt, schist, vein-quartz, Cushendun quartz-porphyry, purple porphyrite of Cushendall, flint and chalk, and even Ailsa Craig eurite.

Flint- and quartzite-boulders occur on the summit of the col between Trostan and Crockalough. The Scottish ice undoubtedly passed over here into the upper part of Glenariff, and thence over the lower col (950 feet) above Parkmore Station into Glenravel.

Glenariff.—Glenariff, the largest and most magnificent of the Glens of Antrim, possesses extremely steep slopes, and the river flows for a considerable distance through a narrow gorge cut in the basalt. Drift-sections are not so frequent in this valley as in those on the north; but such as there are show material similar to that in Glenballyemon, although boulders of schist are much less frequent.

Glenariff, in common with the more northerly glens, was completely filled with the Scottish ice, and the great moorland on the south-east (many square miles of which lie above the 1000-foot contour) was also overridden.

These great glens show very few lacustrine phenomena, nor are there many overflow-channels, and such as exist are of small size. One of some interest lies at the foot of Glenaan, and carries the Glenaan River into the Dall River.

Between Gruig Top and Cross Slieve is a wide, open valley, comparable in size with Glenaan, and this formerly carried the Glenaan River, which in pre-Glacial times was a tributary of the Glendun River. The upper part of this valley east of Knockbane is now streamless, and even at its northern end it carries but a tiny stream formed by the confluence of small tributaries from the flanks of Gruig Top and Cross Slieve.

At one stage during the retreat of the ice the mouth of Glendun was closed, and a lake was impounded in Glenaan; this overflowed the col of Old Red Sandstone on the south, and cut the gorge which now carries the waters of Glenaan into the foot of Glenballyemon, and so, by way of Cushendall, to the sea.

Immediately south of Knockbane is a considerable accumulation of morainic material, and this prevented the Glenaan River from resuming its pre-Glacial channel on the retreat of the ice.

A small overflow-channel cuts across the lower slopes of the spur of Lurigethan, in the neighbourhood of Knockans. This is at a height of 300 feet above O.D., and is the southernmost along this section of the coast.

Small southward-falling channels were probably produced on the steep face above Garron Point; but, if such were the case, they have been long since obliterated by the gigantic landslips that have occurred during post-Pleistocene time.

Glenravel.—During the maximum extension of the Scottish ice a large glacier passed over Parkmore and down Glenravel to

the neighbourhood of Ballymena, and probably still farther south, although the traces of this further movement have been removed by a later glaciation from the south-west.

At a later stage, while considerable quantities of ice were still passing from the north-east down Glenravel, the pressure of the northward-moving ice, in the great central depression occupied by the valley of the River Main and that of the River Bann, had so far increased as to turn the Glenravel glacier northwards, round the spur of Slieverush, near Newtown Crommelin.

This movement is indicated by the direction of the axes of the numerous drumlins (consisting of reddish gravel, which contains, in addition to the local basalt, considerable quantities of schist and gneiss) between Ballynagaboy Bridge and Corkey, and by the drainage-channels which fall north-westwards. These include a channel at 950 feet above O.D. cut through the basalt-spur north of the Aghanageeragh River, and a much larger winding valley (at 750 feet) cutting the spur of Slieverush near the cross-roads, 2 miles south-east of Ballynagaboy Bridge.

The valley of the Skerry Water above Newtown Crommelin contains large quantities of basaltic gravels and boulder-clay with no erratics, and was probably occupied (at all events at a late stage) by a glacier from the great snowfield in the triangle between Trostan, Slievenanee, and Eagle Hill, already mentioned (p. 366).

The northern flank of the Glenravel glacier is marked by a series of channels on the line of the mineral railway from Parkmore to the ironstone-mines near Ballynahavla Bridge at 1050 feet O.D., north of Tuftarney Hill at 850 feet, and two parallel channels at 960 and 940 feet respectively, through the spur of Skerry Hill which terminates in the bold escarpment of the Skerry Rock above the village of Newtown Crommelin.

The direction of the ice-flow is shown by the striations on a sill of dolerite at Tuftarney Hill.

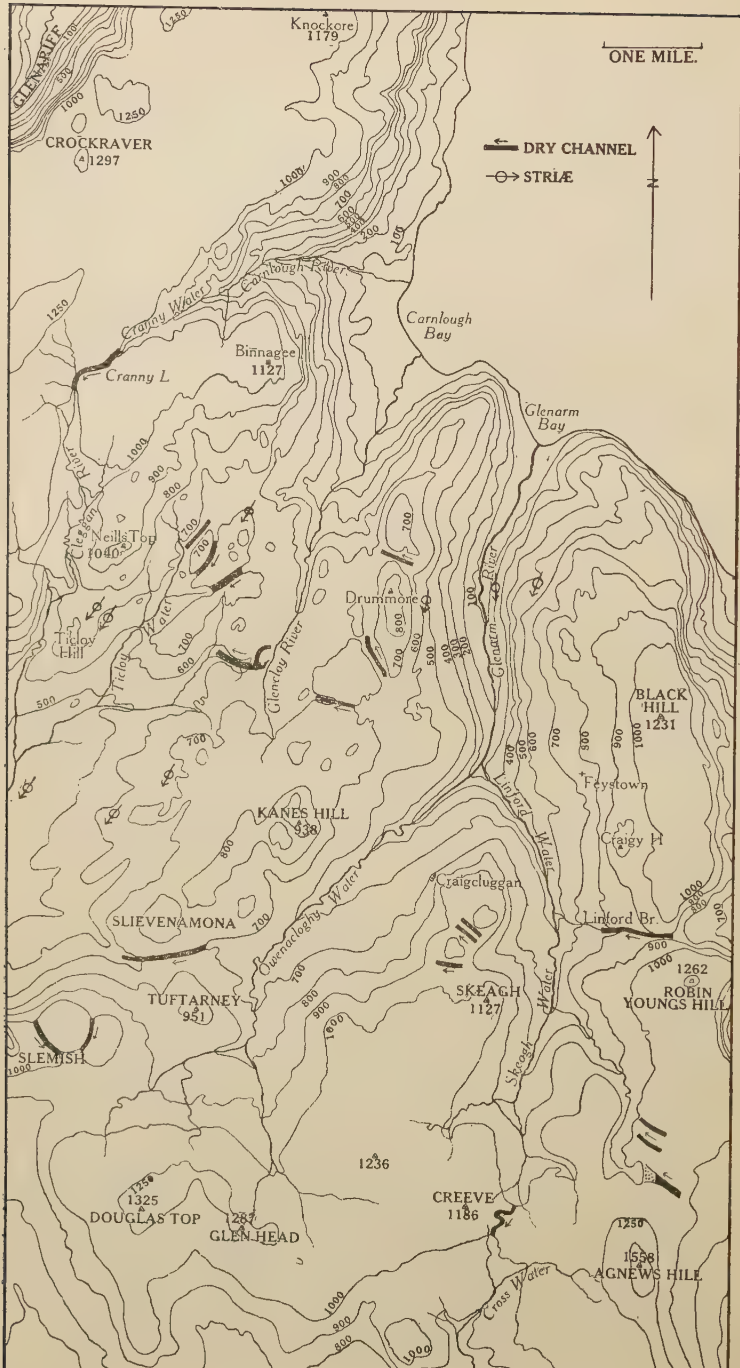
The Southern Area (see map, fig. 4, p. 370).

The rivers flowing down the seaward slope are the Carnlough River, the Glencloy River, the Glenarm River, and several smaller streams farther south, including the Larne Water, the Glynn River, and the Woodburn River. The western slope is drained by the Braid River, the Glenwhirry or Kells River (both tributary to the River Main), and by the Six Mile Water and its tributaries flowing into Lough Neagh.

The valley of the Carnlough River is very deep and gorge-like, and contains a fine waterfall. Its flanks are thickly covered with boulder-clay and gravel up to 1000 feet above O.D. This drift rests upon basalt, and contains boulders of basalt, flint, and chalk, the two last-named having been carried up the valley from the Cretaceous outcrop between the 200- and 300-foot contours.

The upper part of the Carnlough River is known as the Cranny Water, and at its head (at 1075 feet O.D.) is a broad and deep

Fig. 4.



ONE MILE.
DRY CHANNEL
STRIÆ
GLENARIFF
CROCKRAVER
1297
Knockore
1179
Carnlough River
Cranny Water
Carnlough Bay
Binnagee
1127
Cranny L.
Glenarm Bay
Clegagan River
Neills Top
1040
Ticloy Hill
Ticloy Water
Glencloy River
Drummore
Glenarm River
BLACK HILL
1231
Feystown
Linford Water
Craigy H
KANES HILL
938
Craigcluggan
Owenacloghy Water
SLIEVENAMONA
Linford Br.
ROBIN YOUNGS HILL
1262
SKEAGH
1127
TUFTARNEY
951
SLEMISH
Skeagh Water
1236
DOUGLAS TOP
1325
GLEN HEAD
1287
CREEVE
1186
AGNEWS HILL
1558
Cross Water

overflow-channel, cutting through the watershed and falling south-westwards into the headwaters of the Cleggan River, a tributary of the Braid. The Cranny channel is much encumbered with peat, and contains a long narrow lough known as Cranny Lough.

The valley of the Glencloy River is broad and open, and carries the main road from Carnlough to Ballymena. It opens widely towards the north-east, and received the full thrust of the Scottish ice, as is shown by the numerous striated surfaces which occur in the valley itself, on the watershed, and in the valley of the Braid River beyond. All these striæ point between west and south, and in many of them it is easy to ascertain that the ice-flow was from north-east to south-west.

At the head of Glencloy the watershed is cut by four well-marked overflow-channels, all of which fall westwards. Three of these, lying north of the road, connect the Glencloy drainage with the head-waters of the Ticloy Water; while the fourth lies immediately south of the road, and has two branches at its upper end at 650 feet above the sea. The three northerly channels are all at about the 700-foot level, the northernmost having its intake at 660 feet, the middle one (which is 40 feet deep) at 720 feet, and the southernmost one (which is partly filled with peat) at 750 feet. These channels cannot well be explained as the overflows of a lake, with the exception of that which lies at 650 feet on the line of the road. The others were probably formed by streams flowing off the ice, at a time when it stood at the level of the watershed, but was unable to cross it.

The next valley to be considered is Glenarm, which falls from south to north, and at its head divides into two branches—the valley of the Owenacloghy Water on the west, and that of the Linford Water on the east.

Both these valleys contain much drift, quantities of which are also spread over the broad moorlands wherein the streams rise. Thus, on Douglas Top (1325 feet O.D.) and Glen Head (1287 feet) there is drift which appears to contain basalt only, but at 800 to 750 feet (in the course of the Owenacloghy Water) are several cuttings in sandy gravel, roughly stratified, and containing basalt, chalk, flint, and Ailsa Craig eurite; while, lower down the same valley (at 720 feet O.D.) is an excavation in the side of a mound of gravel, which shows current-bedding, and contains basalt, as also numerous pebbles of chalk and flint.

Red boulder-clay containing basalt and flint is exposed in a road-cutting at 600 feet, three-quarters of a mile north of Park Mill, and in several smaller sections in the same neighbourhood.

These deposits are all considerably above the level of the Cretaceous outcrop, and the occurrence of chalk and flint is, therefore, significant.

The valley of the Linford Water and its upper portion (which is called Skeagh Water) also contain great quantities of gravelly

drift, usually current-bedded, and in some places showing signs of a terraced arrangement, although this is not well-marked.

At Linford Bridge is a terrace-like mass of boulder-clay covered by red gravel, and the stream is cutting in gravel; but, although the valley is large, the stream is diminutive and inactive, and the section very poor. The bed of the stream contains basalt and many angular fragments of flint. The terrace is continued along the side of Glenarm as far as the Roman Catholic Chapel at Feystown, although its level falls from 740 feet at Linford Bridge to about 680 at Feystown.

Near the road-junction north-west of Craigy Hill, at a height of 750 feet, is a small lateral moraine, consisting of gravel, which is chiefly basaltic, but contains also chalk, flint, chalcedony, red ironstone, lithomarge, and a purple porphyrite similar to that which occurs on the coast at Cushendall.

The lower part of Glenarm contains great quantities of drift, both boulder-clay and gravel, the contents being basalt, chalk, flint, purple porphyrite, gneiss, schist, and Ailsa Craig eurite, all rocks which occur on the north.

There are several striated surfaces on both sides of the valley, and these, taken together with the erratics, show definite evidence of a movement of ice up the valley. This inference is supported in a most striking manner by the drainage-channels now to be described.

At an early stage during the retreat of the ice, when the upper parts of the plateau were first freed from ice, lakes were held up in both arms of the valley, Owenacloghy Water and Linford Burn. In the earliest stage the glacier flowing up the Owenacloghy Water was still confluent with the ice of Glencloy and the Braid River; but that in the Linford valley on the east was unable to surmount the watershed, and at one stage its front stood across the valley from Skeagh (1127 feet) to Robin Young's Hill (1262 feet), thus holding up a lake in the valley of the Skeagh Water.

This lake overflowed southwards by way of the col at the head of the Skeagh Water, between Creeve (1186 feet O.D.) and Agnews Hill (1558 feet) into the Cross Water, a tributary of the Glenwhirry River. The overflow cut a broad channel, at a level of 1050 feet, which falls south-westwards and winds considerably. Its sides are steep, its floor is covered with peat, and throughout the greater part of its length it is streamless, although at its southern end is a small flow which is tributary to the Cross Water.

The retreat of the ice-edge from Skeagh Hill towards Craigcluggan allowed the waters of the lake to escape westwards into the valley of the Owenacloghy Water, and a channel was cut immediately south of the road from Skeagh Bridge to Owenacloghy Bridge at a height of 960 feet; later, two parallel channels south of the road were cut at 950 and 940 feet respectively.

At this stage, the ice in the North Channel stood against the eastern side of the great ridge Agnews Hill—Robin Young's Hill

—Scawt Hill—Black Hill, which separates Glenarm from the coast, and discharged gravel-laden waters into the eastern arm of Skeagh Water Lake by three channels, at levels immediately above 1000 feet, lying south of the road from Larne to Skeagh Bridge. Each of these channels has a well-marked gravel-delta, at a level of between 950 and 1000 feet at its western end, these deltas marking the water-level of the lake during the period of the overflow by the Skeagh channels into the Owenacloghy Lake. By this time the ice had fallen back sufficiently far to free the upper part of the Owenacloghy valley, and to allow of the formation of a lake in that depression.

At this stage, the Owenacloghy Lake probably drained across the low ground between Douglas Top and Sliemish Mountain, and so by the Douglas Burn into the Glenwhirry River. The col is now occupied by an extensive peat-moss, and so the overflow-channel, if such exists, is completely obscured.

With a further retreat of the ice-front the Owenacloghy and Linford Lakes became confluent, a channel was opened through the col between Robin Young's Hill and Scawt Hill, which discharged much water and gravel into the lake from the eastern ice, and the waters of the combined lakes overflowed westwards at a height of 720 feet, by way of an extremely well-marked streamless channel between Tuftarney Mountain and Slievenamona, into the Braid River.

The waters appear to have stood at about this level for a long period, and it will be remembered that this is also about the level of the terrace mentioned on p. 372, extending from Linford Bridge to Feystown.

Further recession allowed of the escape of the water into the head of Glencloy, by channels at 710, 670, and 630 feet respectively. The first of these is close to the main road from Ballymena to Glenarm, the second midway between that road and the summit of Drummore, and the third north of that hill.

The country between the basalt-escarpment and the North Channel, from Glenarm Bay to Ballygalley Head, consists of outcrops of Chalk, Liassic rocks, and Triassic sandstone and marl. The surface is much broken by landslips, most of which are of post-Pleistocene origin, and (as a result) the glacial phenomena are extremely difficult to follow in detail. All the drift-deposits of this area are of the northern type, and pebbles of Ailsa-Craig eurite are extremely common.

At several places along the coast-road are exposures of Glacial gravels containing, along with the northern erratics, fragmentary marine shells, and in one section at Ballyrudder an extensive collection of shells was made by a committee of the Belfast Naturalists' Field-Club, the section being also carefully described.[1]

Southwards from Ballygalley Head to Larne, and inland to the

[1] Proc. Belfast Nat. F. C. ser. 2, vol. iii (1893) pp. 518–25.

great amphitheatre of Sallagh Braes, the country is covered with the northern drift, the ice having passed southwards along the foot of the escarpment into the valley of the Larne Water, at the head of which stream it passed over into the valley of the Six Mile Water, and thence by Ballynure and Ballyclare, to Antrim and Lough Neagh. This arm of the Scottish ice picked up and carried with it large quantities of the Tertiary rhyolite of Tardree Mountain, boulders of which form so conspicuous an ingredient of the gravels near the town of Antrim.

Through the col between the head of the Larne Water and the Six Mile Water is a large overflow-channel falling south-westwards, and on its flanks are numerous drumlins, the long axes of which are parallel to the channel. The light railway from Larne to Ballymena passes through this channel.

The peninsula of Island Magee was glaciated from north-west to south-east by the Scottish ice, and the deposits (both boulder-clay and gravel) contain Ailsa Craig eurite, basalt, Carboniferous Limestone, chalk, flint, and the purple porphyrite of Cushendall.

From Larne southwards the coastal strip of low ground is drift-covered in many parts, although the covering does not appear to be very thick, as the solid rocks crop out in many places.

In the Glenoe valley a lake was held up by the ice at one stage of its retreat, and its waters overflowed by a well-marked channel into the valley of the Copeland Water on the south.

The Triassic country from Carrickfergus to the foot of the Cave Hill at Belfast is also covered by a variable thickness of northern drift, here made up very largely of the débris of the local Trias.

On the basalt escarpment of Knockagh, near Greenisland, are two dry gaps of the 'in-and-out' type; but the country did not lend itself to the formation of extensive lakes.

IV. The Belfast Valley.

The Belfast Valley and its northward continuation (Belfast Lough) lie on a belt of soft Triassic rocks; they are bounded on the east by the Silurian uplands of County Down, and on the west by the basalt escarpment. The drifts of the valley have been well described in the Geological Survey Memoirs,[1] wherefore it is not necessary to enter into any great detail here.

The lowest deposit appears to be a red boulder-clay with basalt, Silurian grit, chalk, flint, Ailsa Craig eurite, and fragmentary marine shells; but the most conspicuous accumulations are sands and gravels.

Running down the centre of the depression, between the valley of the Lagan and that of the Blackstaff, is a broken ridge of red sand, the 'Malone Sands' of the Geological Survey. These 'sands' consist almost entirely of re-assorted Triassic sand and marl.

[1] 'The Geology of the Country around Belfast' Mem. Geol. Surv. Ireland, 1904.

The surface of the deposit is hummocky and moraine-like in contour, but this is probably due to the erosion of the sands by the powerful springs which arise in many places, and cut deep irregular valleys. The sands are usually stratified, and contain many beds of laminated clay, which in some cases (as at Stranmillis) is used for the manufacture of bricks.

Coarse sands and gravels of the ordinary fluvio-glacial type occur higher up the valley in the neighbourhood of Lisburn. These are well exposed in gravel-pits west of that town; and in one of these excavated in a mound near Causeway End, the following erratics occur:—basalt, Triassic sandstone, flint, chalk, reddish quartz-porphyry, Carboniferous sandstone with veins of calcite, black limestone, syenite, vein-quartz, dolerite, glauconitic chalk, Tardree rhyolite, mica-schist, Silurian grit, quartzite, red granite (Tyrone), gneiss, fossil wood from the Lough-Neagh Clays, greenish-grey gabbro, Ailsa Craig eurite, and fragments of marine shells.

The sands are red, and obviously contain much Triassic material; and nearly all the erratics have come from the north. The pebbles of rhyolite from Tardree travelled across the Templepatrick area, and along the strip of country between Lough Neagh and the Belfast Hills, by way of Stoneyford.

Farther west, in the neighbourhood of Moira and Soldierstown, erratics from Tyrone are very common; and this country lies within the area invaded by the western ice at a late stage of the glaciation.

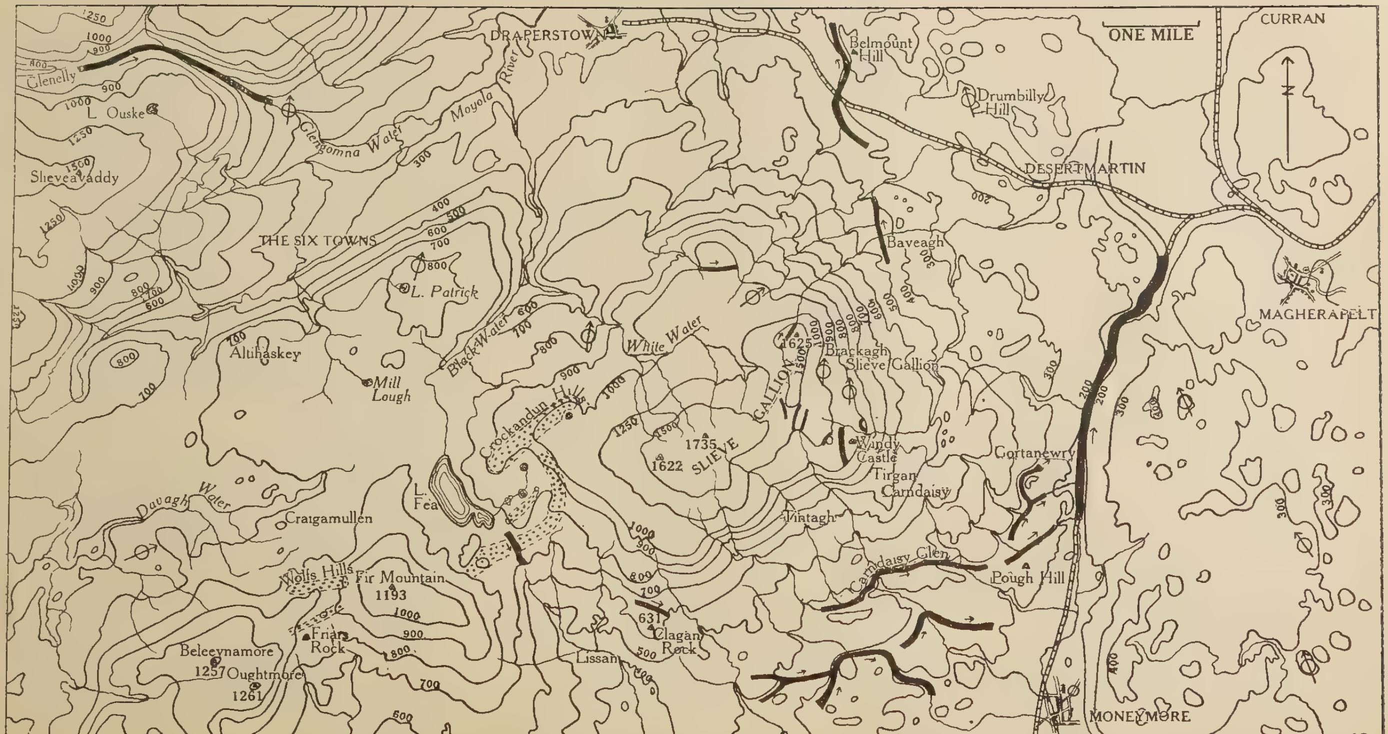
The Tyrone erratics include epidiorite, hornblende-syenite, Carboniferous Limestone, coarse hornblende-diorite, white quartzite, and red quartz-porphyry, all of which can be matched from rocks occurring in the country north-west of a line drawn from Magherafelt to Six Mile Cross in County Tyrone.

V. The Area between Slieve Gallion (Tyrone) and the Belfast Valley.

This is the basin of Lough Neagh, and is bounded on the west by Slieve Gallion (1735 feet; see map, fig. 5, p. 376), which consists of granitoid rocks, crystalline schists, and Carboniferous sediments, surmounted by an outlier of Chalk, capped with Tertiary basalt; and by the high land south-west of it running by Fir Mountain (1193 feet), Oughtmore (1261 feet), through Pomeroy and Slievemore (1037 feet) to Slieve Beagh (1221 feet); finally, on the east by the basaltic Belfast Hills.

This area was first invaded by the Firth-of-Clyde glacier, as is proved by the occurrence of Ailsa Craig eurite in the drift deposits at the mouth of the Blackwater, at the extreme south-western corner of Lough Neagh, at Armagh, and at Monaghan. The pebbles of Ailsa Craig eurite are mingled in the deposits with many rocks from the Slieve Gallion axis, indicating that they are *remaniés* from the deposits of the earlier glaciation, and have been incorporated with the proceeds of the later extensive glaciation from the west.

Fig. 5.



ONE MILE
CURRAN
DRAPERSTOWN
Belmount Hill
Drumbilly Hill
DESERTMARTIN
MAGHERAFELT
Glenelly
L. Ouske
Glengomna Water
Moyola River
Slieveavaddy
THE SIX TOWNS
L. Patrick
Baveagh
Altinaskey
Mill Lough
Black Water
White Water
Brackagh
Slieve Gallion
GALLION
SLIEVE
1735
1622
1625
Crockandun Hill
Windy Castle
Tirgan
Carndaisy
Cortanewry
L. Fea
Davagh Water
Craigamullen
Tintagh
Carndaisy Glen
Pough Hill
Wolfs Hills
Fir Mountain
1193
Friars Rock
631
Clagan Rock
Lissan
Beleevnamore
1257
Oughtmore
1261
MONEYMORE

How far the northern ice penetrated in this south-westerly direction it is at present impossible to say, so long and severe was the south-eastward ice-flow which followed that all traces beyond occasional erratic pebbles have been removed. For this reason the features which will now be described are those due to the western ice.

Slieve Gallion (Ordnance Survey, 1-inch map, Sheets 26 & 27; see also map, fig. 5) forms the eastern bulwark of a mass of high ground made up of an igneous and schistose complex, extending in a north-westerly direction to the Sperrin Mountains and south-westwards to Carrickmore and Beragh. This mass of high ground will be designated the Tyrone Axis.

The ridge of which Slieve Gallion forms the highest point is continued in a south-westerly direction by the summits of Fir Mountain (1193 feet O.D.) and Beleevnamore Mountain (1257 feet), and north of this line of hills lies a great undulating plateau in which is the valley of The Six Towns.

Up to a very late period of the glaciation this area was occupied by a large glacier which flowed north-eastwards over the site of Draperstown. That flow is indicated by the striations, by the transport of local material, and by the fine series of lateral moraines in the neighbourhood of Lough Fea. A very good example of 'crag and tail' is to be seen at Craigamullen, 2 miles west of Lough Fea, where boulders of the local pyroxenic rocks can be traced in enormous numbers north-east of the outcrop.

This Six Towns Glacier pushed tongues of ice through the valleys between Slieve Gallion and Fir Mountain, and between Fir Mountain and Beleevnamore, wherefore frontal moraines of these lobes, produced during the retreat, form very conspicuous features near Lough Fea and at Wolfs Hills and Friars Rock.

A hornblende-granite,[1] which occurs *in situ* near Lissan, has a very wide and peculiar distribution. It has been carried up the valley past Lough Fea, is present in considerable quantity in the moraines known as the Crockandun Hills, and a train of its boulders runs north-eastwards into the valley of the White Water. This indicates a movement of ice through the Lissan valley from south-east to north-west at an early stage; but the frontal moraines mentioned above indicate a flow in the opposite direction at a later period.

There is no doubt that the ice north-west of the great ridge was confluent with that on the south-east at one stage, and ice may well have flowed through the Lissan valley first in one direction, and then in the other, in response to varying thrusts, as one or other of the great glaciers was in the ascendancy.

In addition to the distribution described above, the Lissan granite is to be found abundantly in the drift south-east and east of Slieve Gallion: for instance, at Moneymore, and on the shores of Lough Neagh at Ballyronan and Toome.

[1] Indicated on the Geological Survey map as 'syenite'.

That the main flow of ice in the later stage of the glaciation, in the Moneymore, Cookstown, and Magherafelt area, was north-eastward is shown by abundant evidence, both in the transport of erratics and in the distribution of the overflow-channels.

There are numerous small dry gaps, all falling north-eastwards, in the neighbourhood of Windy Castle, a spur of Slieve Gallion. The highest of these channels is at 1300 feet above Ordnance datum.

At lower levels, between 200 and 400 feet, is a series of very broad channels, which were formed along the edge and probably near the termination of the much shrunken glacier at a later stage, when, however, the ice was still flowing northwards in this district. These channels are marked in fig. 5 (p. 376), and they are cut partly in the solid rocks of the district, and partly in drift. Often the outer side, away from the ice, is of rock, while the inner is of boulder-clay and gravel; but the channels all have the typical form of glacial drainage-gaps, being deep, steep-sided, flat-floored, and altogether out of proportion to the streams which now flow through them, many being actually streamless.

The two largest of these channels are Carndaisy Glen and Gortanewry Glen. In addition to the drainage from the ice, the great gorge of Carndaisy Glen must have carried all the water from that part of Slieve Gallion which lies between Clagan Rock on the south-west and Carndaisy on the north-east: that is, the townlands of Dirnan, Derryganard, Letteran, and Tintagh; and at one stage the same waters flowed through Gortanewry Glen, although at a later stage they escaped into the low ground in the neighbourhood of Pough Hill. All these channels were tributary to a very large northward-flowing stream which cut a broad channel, now occupied by the railway between Magherafelt and Moneymore, along the foot of the basalt escarpment.

The basalt country between the railway and the western shore of Lough Neagh is covered by mounds of gravelly drift, and both the axes of the mounds and the striations on the basalt indicate a north-north-eastward flow. Over the whole of this area are scattered boulders of the Lissan granite and other rocks from the Slieve Gallion complex, showing that the ice which passed over it came originally from the west, but was deflected northwards and north-eastwards. This deflection and its cause will receive further consideration later.

The country between Moneymore and Cookstown is covered by mounds of gravelly drift containing abundant western erratics.

In the latitude of Cookstown the Ballinderry River cuts through the basalt escarpment at Coagh, and flows by a narrow valley into Lough Neagh. I am of opinion that this gap in the escarpment owes its origin to glacial drainage, although actual proof of this is not forthcoming. If this surmise be correct, the glacial waters would at this stage abandon the Moneymore-Magherafelt channel, and find exit by this shorter route to the lough.

The Cookstown and Dungannon Area.

This area, especially in its southern part, is characterized by enormous moraines, which are considered to be frontal moraines produced by the western ice during the period of its final retreat. There are also extensive spreads of current-bedded sands and gravels.

A large sand-pit in the town of Coalisland shows a deep section in stratified sands and gravels, which are somewhat contorted. The pebbles and boulders include schist, flint, burnt flint, red sandstone, basalt, chalk, Carboniferous Limestone, epidiorite (Tyrone Axis), and granites, also boulders of white Lough-Neagh Clays, with numerous masses of silicified wood derived from the same deposit.

Dungannon stands on one of the great series of moraines above mentioned, and at the Tyrone Brickworks (about a mile and a half north of the town) is a section that shows blue and red boulder-clay overlying red stratified clay and sand which contain ironstone-nodules and lignite from the Lough-Neagh Clays, the outcrop of which lies east of the section.

The boulder-clay contains much Carboniferous shale (local), big and well-striated boulders of Carboniferous Limestone, Tyrone diorites and epidiorites, schist and granites, and a porphyrite from the same region on the west. The lower deposit of stratified sand and clay, with its material derived from the Lough-Neagh Clays on the north-east, appears to be a relic of the glaciation by the Scottish ice; while the boulder-clay above was undoubtedly produced by the later flow from the west.

West of Dungannon, as the hilly country is approached, the moraines become still more conspicuous, the largest in the district being that running through Mullaghbane ($2\frac{1}{2}$ miles south of Castlecaulfield), Castlecaulfield, and Donaghmore, to the neighbourhood of Cookstown. West of this line the moraines can be seen, rank behind rank, for several miles. They consist almost entirely of material from the west; but at several localities, as, for example, in a quarry opposite the castle at Castlecaulfield, a purplish boulder-clay contains, in addition to the western rocks, numerous pebbles of flint which can only have been derived from the country on the north-east, again indicating the passage of the Scottish ice over this area. Numerous angular boulders of basalt, similar to the Tertiary rocks of the Antrim Plateau, also occur in this pit; but their angularity indicates, in all probability, their origin from some local dyke.

The Country south of Lough Neagh.

South and south-west of Lough Neagh is a large tract of land lying below the 100-foot contour, and occupied by peaty and swampy flats. From the peaty flats emerge many drumlin-like masses of glacial deposits, chiefly boulder-clay, but with patches of morainic gravels, as at Hunts Corner, Maghery, and Charlestown.

When examined on the ground, these mounds are seen to possess a roughly linear arrangement, the lines running approximately

north and south, and a careful study of them has led me to the conclusion (in which Mr. W. B. Wright, who visited a portion of this country in my company, concurs) that they represent frontal moraines similar to, though of less magnitude than, those of the Dungannon-Castlecaulfield area.

The gravels contain purple porphyrites, diorites, red granite and quartz-porphyry, schist and gneiss, all from the Tyrone Axis; limestone yielding *Lithostrotion*, red limestone, red sandstone, flint, burnt flint, chalk, ironstone-nodules from the Lough-Neagh Clay (local); and Ailsa Craig eurite. Here again is evidence of the earlier glaciation from the north-east, followed by that from the west.

Still farther south, on the rising ground near the city of Armagh and the village of Rich Hill, these morainic accumulations are still more conspicuous, and the country from Markethill to Tanderagee is of similar character.

The Area east of Lough Neagh.

It has already been mentioned (p. 375) that in the neighbourhood of Moira and Soldierstown are to be found boulders of rocks from the Tyrone Axis, and these can be traced for some distance north-eastwards; but they appear to be absent beyond a line drawn from the mouth of the Crumlin River through Glenavy to Lisburn.

The shores of Lough Neagh are in many places covered with shingle, the pebbles of which have been derived from the local drifts, which sometimes form low cliffs bordering the beach. These beaches make excellent collecting-grounds for the study of the contents of the drift-deposits, and careful examination has failed to reveal a single pebble of the Tyrone rocks, so common farther south, on the lough side from Moore's Quay northwards by Ardmore Point, Dunore Point, and Antrim Bay; indeed, it is not until the neighbourhood of Randalstown is reached that they again appear.

At Dunore Point the shingle consists almost entirely of basalt; but there are a few small pebbles of chalk, flint, rhyolite, quartzite, and vein-quartz, also Ailsa Craig eurite. Tyrone rocks are absent.

The Scottish ice has already (p. 374) been traced inland from the neighbourhood of Larne by Ballynure and Ballyclare, and this glacier moving in a south-westerly direction extended to the Belfast Hills.

Striations on basalt about 2 miles south of Templepatrick run south 25° west, and another set on Armstrong's Hill, a spur of Divis, from east to west.

On the summit of Divis (1567 feet O.D.) there is little or no drift, but small angular flints are to be found right up to the cairn. These flints can only have been derived from the Chalk outcrops near the foot of the eastern basalt-escarpment, some 700 feet lower, and about a mile away to the north-east; they indicate that the summit was overridden at the period of maximum extension of the Firth-of-Clyde glacier. Flint-pebbles are also

common on the col between Divis and Wolf Hill, at a level of 1100 feet.

Cave Hill, the bold escarpment of basalt which overlooks Belfast, must also have been covered during the period of maximum development, as were Squires Hill and the long ridge which runs from it in a north-westerly direction by McIlwhans (1128 feet) and Boghil (917 feet) to Lyles Hill (747 feet). This ridge is cut through by several dry gaps, which carried off the drainage from the ice-front at a late period of its retreat, and the northern spur of McIlwhans is cut by three such channels.

The valley between Cave Hill and Knockagh contains great quantities of boulder-clay, characterized by the presence of the local basalt with chalk, flint, and various Scottish rocks (including Ailsa-Craig eurite).

The district between Templepatrick and Antrim is covered with boulder-clay containing basalt, flint, and Ailsa Craig eurite; to these are now added numerous pebbles of the Tertiary rhyolite, of which there is a large outcrop on the north-east in the neighbourhood of Tardree Mountain, and a smaller one at Templepatrick.

Resting upon the boulder-clay and in places on the basalt are great mounds and sheets of stratified and current-bedded sands and gravels. These are well seen in section in the large ballast-pits on the side of the railway, a mile south-east of Antrim Station. Here the section is 30 feet deep in sands and gravels, with thin beds of clay. The deposits are stratified and current-bedded, but the stratification is somewhat confused. The large size of many of the boulders shows that the waters which transported the materials must have possessed great power.

The big boulders are principally of basalt and rhyolite, the latter being present in considerable quantity. There are also fairly large pieces of chalk and flint. The small pebbles include basalt, rhyolite, chalk, flint, lithomarge, silicified wood, Silurian grit, and Ailsa Craig eurite.

A careful examination of these extensive sections failed to reveal any rocks from the Tyrone Axis.

Immediately south of the area just described lies an undulating tract of basaltic country, in places heavily covered with boulder-clay and gravels which, however, thin out frequently on the higher ground, where the covering is scanty or the basalt actually comes to the surface.

Fine sections of boulder-clay are exposed along the course of the Clady Water, a stream that rises on the slopes of Divis, and flows north-westwards to the Six Mile Water, which it joins at Dunadry.

Near Clady Bridge are several sections in red boulder-clay, which is at least 30 feet thick, and contains only basalt, chalk, and flint. On the Geological Survey map this area is described as basaltic boulder-clay on chalky boulder-clay; but I have been unable to find any trace of the upper boulder-clay without chalk in any of these sections.

About 2 miles west of Clady Bridge the road crosses a well-marked glacial drainage-channel, which is marked on the Geological Survey map of the Belfast district. It is deep and wide, with steep sides and a flat floor, and doubtless carried the drainage from the ice-front at a period slightly preceding the retreat to the line Squires Hill–Lyles Hill (previously mentioned on p. 381). The stream now flowing through this channel is very small.

Deposits similar to those last described cover the country on the south as far as the neighbourhood of the railway from Glenavy to Lisburn, where the rocks from the Tyrone Axis come in (see p. 375).

The Northern Shore of Lough Neagh.

It has already been stated that the drift-derived shingle on the shores of Antrim Bay is devoid of rocks from the Tyrone Axis; but in the neighbourhood of Shanes Castle and Randalstown they make their appearance in force.

A section at the works of the Old Bleach Linen Company at Randalstown shows reddish-brown boulder-clay 20 feet thick, containing boulders of basalt, Carboniferous sandstone, Carboniferous Limestone, diorite, a coarse pyroxenic rock, epidiorite, a bright-red granite, boxstones (ironstone from the Carboniferous rocks), pink quartz-porphyry, and mica-schist (all from the Tyrone Axis and the country west of Dungannon and Cookstown), as well as flint and vein-quartz. I found no Scottish rocks in this section, and the Tardree rhyolites also appear to be absent.

Similar boulder-clay is seen in a stream-section on the road from Randalstown to Cookstown Junction, a mile east of the former place; and Tyrone rocks occur as isolated boulders on the roadside to within half a mile of Cookstown Junction Station.

When we cross the main line of the Midland Railway from Antrim to Ballymena, the Tyrone rocks are no longer to be found; but very large boulders of basalt and dolerite occur in the village of Farranflugh, half a mile east of the line, and the Tardree rhyolites are also present.

The line of railway here marks the eastward limit of the western ice, but not the western limit of the Scottish sheet, as Ailsa-Craig eurite is found in small quantities much farther west; for example, Mr. Robert Bell has recorded it at Drumanewy, 2 miles west of Randalstown. In this, and in many other cases, the Ailsa-Craig rock is associated with Tyrone and other western rocks, and is considered to be remanié from the deposits of the earlier Scottish glaciation.

As we follow the northern coast of Lough Neagh westwards from the mouth of the River Main, near Shanes Castle, brown boulder-clay is seen at intervals along the foreshore, and, as at Portlee, Tyrone rocks are present.

In the bay west of Conn's Point is a cliff of basalt capped by red sandy boulder-clay, which contains boulders of basalt, schist, diorite, vein-quartz, and quartzite.

In the neighbourhood of The Three Islands is an extensive striated surface of basalt, on which the striæ run in several different directions: namely, south to north, south-south-east to north-north-west, and south-south-west to north-north-east. Those from south-south-east to north-north-west cross, and in some cases obliterate the others, thus representing the latest movement. Other striated surfaces with striæ running in the same general directions occur at Gawley's Bay, Pullan Bay, and Doss Bay farther west.

At Pullan Bay are many big boulders on the beach, and these include basalt (local), granite (Slieve Gallion), diorite, pyroxene-rock, red granite, schist, andesite, and gneiss (all from Tyrone), and also chalk, flint, and vein-quartz. The beach is bounded by low cliffs of brown boulder-clay, which also occurs *in situ* on the shore; and it was from this deposit that the large boulders were derived.

A mile north of Staffordstown Station, in the same area, occur boulders of basalt, pink quartz-porphyry, andesite, pyroxene-rock, chalk, and flint, all derivable from the south-west.

VI. The Central Depression north of Lough Neagh.

(*a*) The Valley of the Lower Bann (map, fig. 6).

In order to follow the later glaciation of this area it will be necessary first to consider the deposits and drainage-channels in the country north of Slieve Gallion, and in the neighbourhood of Draperstown, Magherafelt, Castledawson, and Maghera (figs. 5 & 6, pp. 376 & 384).[1] This is a low-lying basin drained by the Moyola River and its tributaries, and I saw at once, on visiting the area, that it had been covered by ice from the south and south-east.

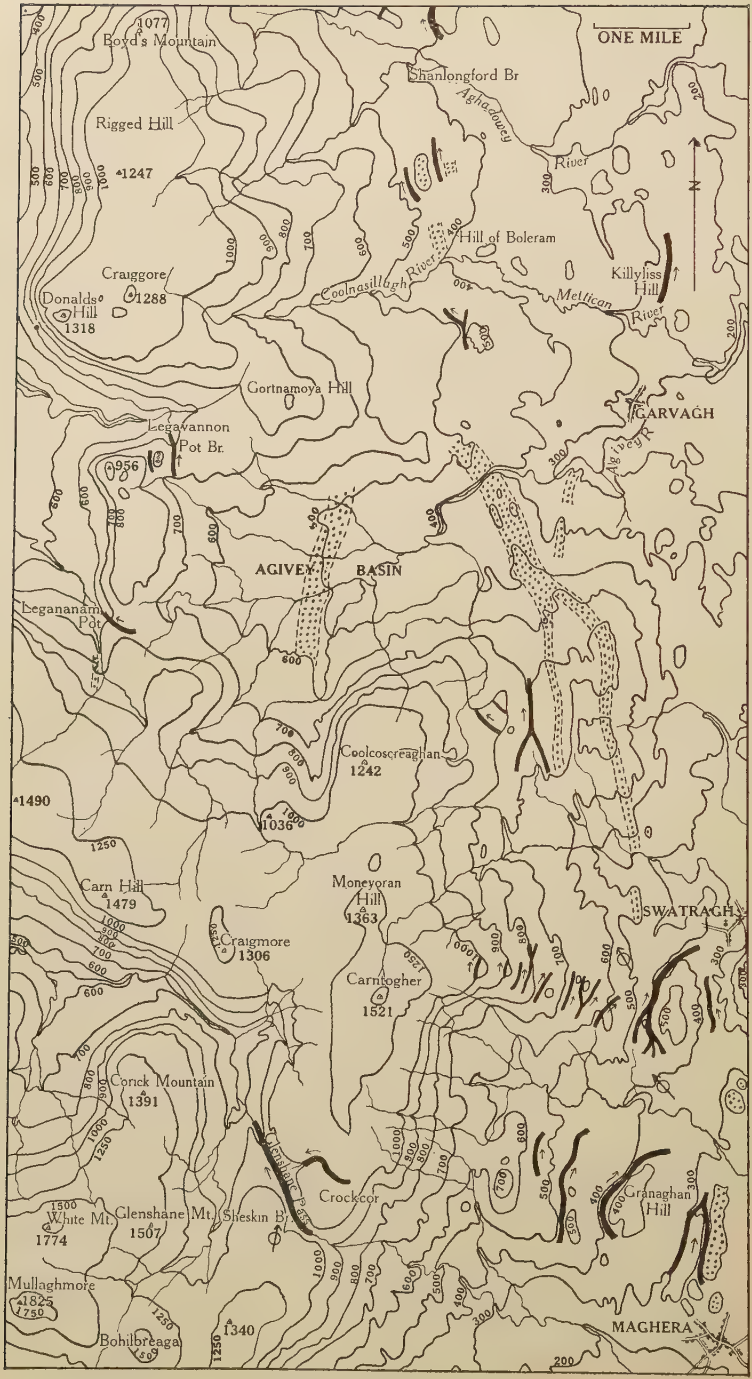
It has already been noted that a great glacier flowed in a north-easterly direction from the valley of The Six Towns and the high ground north-west of Slieve Gallion, also that ice flowed in a northerly direction along the eastern face of Slieve Gallion, over the country between Moneymore and Magherafelt.

It was obvious on the ground that the ice-flow from the direction of The Six Towns, and from Glenelly and the country on the west, had been extremely powerful, and my first investigations in this district were undertaken with the view of ascertaining, if possible, the height which the ice of this stream had reached on the hills north-west of the Draperstown basin. Little information could be gained on this subject from Slieve Gallion (1735 feet O.D.) except the fact that that mountain had been completely overridden.

North and west of Draperstown are several passes leading over

[1] In fig. 6 the place-name 'Granaghan Hill' should appear on the hill immediately north of that on which it is erroneously indicated: that is, nearer Swatragh.

Fig. 6.



ONE MILE
N
Boyd's Mountain
1077
Rigged Hill
1247
Shanlongford Br
Aghadowey River
Hill of Boleram
Coolnasillagh River
Killyliss Hill
Mettican River
Craiggore
1288
Donalds Hill
1318
Gortnamoya Hill
GARVAGH
Agivey R.
Legavannon Pot Br.
956
AGIVEY BASIN
Legananam Pot
Coolcoscreaghan
1242
1490
1036
Carn Hill
1479
Moneyoran Hill
1363
SWATRAGH
Craigmore
1306
Carntogher
1521
Corick Mountain
1391
Glenshane Pass
Crockcor
Granaghan Hill
White Mt.
1774
Glenshane Mt.
1507
Sheskin Br.
Mullaghmore
1825
1750
Bohilbreaga
1340
MAGHERA

the chain of the Sperrins and the elevated edge of the basalt-plateau into the valley of the Roe and the Lough Foyle depression, and an investigation of these seemed to promise a solution of the problem.

Prof. Charlesworth had informed me that there was an overflow-channel at a height of 870 feet, leading over from the head of Glenelly into the headwaters of the Glengomna Water, a tributary of the Moyola; I subsequently found that the col between Crockbrack (1735 feet) and Craigbane was cut by a dry gap falling north-eastwards at a level of 1250 feet, and that the drift-deposits extend up to the 1250-foot contour-line on the sides of Craigbane.

There are two roads leading over the col between Mullaghmore (1825 feet) and Spelhoagh (1875 feet), the western one into the valley of the Finglen River, and the eastern by Barony Bridge (1176 feet) to Dungiven. The col is thickly covered with brownish sandy drift, containing masses of Carboniferous conglomerate, schist, and vein-quartz, all of local origin.

At a height of 1000 feet on the south side of the pass, the Altallack River cuts through a great moraine; and at about 1150 feet above O.D., between Barony Bridge and Labbyheige Bridge, is another moraine, which consists of material derived from the south and south-west.

These facts indicate that the ice stood sufficiently high to override the col between the heads of the Altallack and Altnaheglish Rivers. This col is also cut by an enormous overflow-channel which falls north-westwards, and is streamless. There are, moreover, great morainic accumulations on the western road near Glenedra Lodge, at a height of about 1100 feet.

On the southern face of the spur of Spelhoagh, connecting that mountain with Craigagh Hill, is a large corrie with precipitous cliffs, the summit of which stands at about 1500 feet above Ordnance datum. These cliffs are cut by two large dry gaps, which are continued by very broad dry channels down the northern slope of the spur into the valley of the Glenedra Water.

It is thus evident that the ice at one period stood against the southern flanks of Oughtmore and Spelhoagh at a level of at least 1500 feet; and, as this would give an ample force to account for the phenomena which I had observed in other parts of the country, and as I was now within Prof. Charlesworth's territory, I did not pursue these investigations any farther.

As has already been stated, Slieve Gallion was completely overridden at the maximum extension of the ice; but at a later stage it was a nunatak dividing the ice of The Six Towns Glacier from that of the Moneymore Valley. Both these streams were moving northwards, and they became confluent at the northern end of Slieve Gallion, where enormous masses of morainic material, forming a triangle with its apex towards the north, were accumulated. This morainic material rests upon a tough red boulder-clay containing rocks from the Slieve Gallion area, and extends from

Belmount Hill (377 feet) southwards across the Draperstown Railway to the neighbourhood of Baveagh.

The striations on Brackagh Slieve Gallion, on Drumbilly Hill, north-west of Desertmartin, in the area south of Magherafelt, and on the northern shores of Lough Neagh, all indicate a movement of ice in a north-north-easterly direction down the valley of the Lower Bann, and the course of this glacier will now be traced towards the northern sea. Its width extended from the basaltic hills Coolnasillagh Mountain (1340 feet) and Carntogher (1521 feet) on the west, over the valley of the Bann at Portglenone and the high ground east of it, into the neighbourhood of Ahoghill and Grace Hill in the valley of the River Main, where it was confluent with Scottish ice from the valleys east and north-east of Ballymena, which it was powerful enough to deflect northwards.

The western margin of the Bann Glacier, and its deposits in the valley of the Bann will first be considered. The marginal phenomena are best seen on the basaltic spurs which project eastwards from the left slope of the valley.

Whether the ice passed over the summit of Coolnasillagh there is no direct evidence to show; but, if we judge from the direction of the striations, south-south-west to north-north-east, near Sheskin Bridge in Glenshane Pass, this seems highly probable.

That an ice-lobe penetrated the pass from the south-east is indicated by accumulations of gravelly drift and the existence of two overflow-channels, one on the line of the pass at 946 feet, and the other north of Crockcor at an altitude of slightly over 1000 feet. These channels both fall north-westwards, and terminate at about 850 feet in Glenshane, at which level there are large spreads of gravel that probably mark the level of a glacier-lake.

The first of the basaltic spurs mentioned above is that north of the valley carrying the road from Maghera to Glenshane Pass, and between it and the Pullan Water. It is cut through by a number of channels, the most marked of these being at 560, 480, 380, 320, and 280 feet respectively. They all fall northwards, and took the overflow of a lake impounded between the ice and the spur, at successive stages of the retreat. The largest of the channels is that at the 380-foot level, which contains Killelagh Lough. This channel is cut in basalt, is 100 feet wide, and has a flat floor. The lough is on the watershed which is at the southern end of the channel, and small streams flow from both ends of the lough.

Running parallel to the road from Maghera to Swatragh is a lateral moraine of considerable size, which lies between the road and the end of the spur.

The next ridge in succession is a spur of Carntogher, and the ice impounded a lake in the valley in which Carntogher House stands, between it and the spur previously mentioned. The valley contains much dark brown boulder-clay, in which there are several stream-sections, containing many small boulders of schist, vein-quartz, and basalt, with occasional fragments of flint: this material is all local. The drift extends up the Pullan Water to

a height of about 1100 feet, above which the mountain is thickly covered with peat.

The Carntogher spur is cut by a large number of channels, some of which are well marked and fall northwards. This spur consists of Tertiary basalt, and the fact that the ice passed over it is proved by the occurrence of boulders of schist up to an altitude of 1000 feet. A new road for the conveyance of peat has been cut along the crest of the spur, and this provides an opportunity of examining the drift which occurs in pockets beneath the peat: it contains basalt, schist, and flint.

The strongly marked channels, as mentioned above, fall northwards; but there are also many others, partly obliterated, which fall in a southerly direction, and may possibly be traces of the first glaciation of the valley by the Scottish ice.

The principal northward-falling channels are at 820 feet (in which are boulders of Slieve Gallion granite), 790 feet, 580 feet, and a very large channel with a number of branches at its head at about 480 feet. This last lies west of Granaghan Hill, formed by a massive sill of dolerite which is strongly jointed, and has been torn up by the ice, the loose blocks being scattered by thousands over the country on the north. This and several other smaller examples of 'crag and tail' indicate that the latest movement was from south to north; but this area is somewhat perplexing, as many of the rocks have the appearance of being moutonné from the north. That circumstance, taken in conjunction with the southward-falling channels mentioned above, leads me to suppose that we have here some traces of the earlier glaciation from the north which have not been entirely obliterated.

On the line of the Maghera-Swatragh road which passes the end of the spur are several drumlin-like mounds: these I take to be the continuation of the lateral moraine mentioned on p. 386.

The next spur to be considered is that running in a north-easterly direction from Coolcoscreaghan (1242 feet), on which there are two channels above Dowlins Bridge at about 830 and 820 feet respectively; also a more strongly-marked one at 750 feet, which cuts several gorges in the Dalradian schists, and is streamless. These all fall northwards.

On the lower portions of this spur are other channels; but these are rendered difficult of interpretation by vast accumulations of morainic material, forming a series of parallel ridges which run north and south. As they are traced northwards, these ridges coalesce to form a gigantic lateral moraine, which crosses the valley of the Agivey River.

The portion of the Agivey Valley above the town of Garvagh occupies a basin-shaped hollow, bounded on the south by Coolcoscreaghan, Ashlamaduff Hill, Carn Hill, and Benbradagh; and on the north by Gortnamoya Hill, and its spur which terminates in Rabbit Hill at Garvagh. The western end of the basin is partly closed by a basaltic ridge, which forms part of the great western

escarpment, and rises into summits at 893, 900, and 956 feet respectively.

North and south of this ridge are passes leading over into the Roe Valley, and each of these carries a glacial drainage-channel terminating westwards in a dry waterfall, below which is a short gorge. These are locally known as 'pots'; the northern one is at Pot Bridge and is called Legavannon Pot, while the southern one is called Legananam Pot. These 'pots' undoubtedly took the drainage of a lake temporarily held up in the Agivey Basin by the ice of the Bann Valley.

The floor of the Agivey Basin lies between the 400- and the 500-foot contours, and is intersected by several lines of moraine which are partly buried by peat and alluvium. These I take to be lateral moraines of the Bann Valley Glacier, and I believe that they belong to the same series as that which will now be described.

The lower end of the basin is closed by a great lateral moraine of the Bann Valley Glacier which stretches from the spur of Coolcoscreaghan on the south to the high land west of Garvagh on the north. The river has been forced over to the northern side of the valley, and escapes by a gorge 100 feet deep cut through basalt.

There is a section in the moraine on the right bank of the river, immediately below Errigal Bridge, which shows brown sandy drift resting upon basalt; and in gravel-pits close by similar material is exposed, containing basalt, schist, flint, vein-quartz, and a coarse dioritic rock from the Tyrone Axis. The sand is very 'dirty', and there is some laminated clay without stones.

The western (outer) face of the moraine is very steep, and about 100 feet high, and a small stream flows northwards through the flat ground at its foot to join the Agivey immediately above Errigal Bridge.

The morainic belt is about a mile wide, and at its inner edge near Lower Magheramore is a large gravel-pit, showing a section 30 feet deep in gravels which dip south-westwards. The materials are similar to those of the great moraine, and include basalt, ironstone, schist, white granite, vein-quartz, and Slieve Gallion granite.

Near the head of the Agivey Basin, on its southern side, are long gentle slopes leading up to Carn Hill and Benbradagh. These slopes include the townlands of Brishey, Evishagaran, and Cruckanim, and are heavily covered with drift, sections of which are exposed in numerous stream-courses. The drift consists of red boulder-clay below and gravels above. The material is all such as could be derived from the immediate neighbourhood.

The streams contain only basalt-boulders in their upper parts, but some of schist appear lower down, as soon as the schist outcrop has been reached. The ice which brought this material must have come from the south-west, but whether from the ridge itself or from the country beyond, I was unable to ascertain.

In the valley of the Gelvin River below Legananam Pot, there is an extensive lake-terrace at 500 feet O.D., consisting of red sandy

stratified drift in which the stream has cut several sections. There is also an upper terrace at 700 feet a quarter of a mile south-west of the 'pot,' and this bears on its surface a small moraine-like ridge. These features belong to the area investigated by Prof. J. K. Charlesworth, and their explanation rests with him.

The country between Garvagh and Kilrea is deeply drift-covered, the material lying in irregular mounds strongly suggesting morainic country; but in several places, as at Moneydig Hill, long ridges are produced by the outcrops of dolerite-sills in the Tertiary basaltic series. Streams have cut deep valleys in the drift in many places, and some of these are out of proportion to the present drainage, as at Grove Bridge, 4 miles west of Kilrea. The valleys fall northwards, and were probably excavated by water flowing away from the melting ice-front during the period of retreat.

Another of these valleys lies at the foot of the western face of the dolerite escarpment at Moneydig Hill.

At Kilrea are several large gravel-pits, and in one of these near the railway, where the road from Garvagh enters the town, is a section about 25 feet deep. The gravels contain much basalt with smaller quantities of schist and vein-quartz, as well as some flint and chalk, lithomarge, hornblende-diorite, and red granite from the Tyrone Axis. I also found several pebbles of Ailsa Craig eurite. In the lower part of the section the gravels are strongly current-bedded, the dip of the laminæ being northward; while in the upper part they are horizontally, though somewhat roughly stratified. There is a capping of brown boulder-clay with few stones above the gravel at the southern end of the pit; while occasional beds of very fine gravel, some of which are black with basaltic débris, others clear yellow, occur in the current-bedded portion of the coarse gravels.

Another gravel-pit is to be seen near the river-bank on the Kilrea side of Port Neal Bridge. The bedding is confused, the gravels are distinctly morainic in character, and beds of sand occur in the section, which is 30 feet deep. The contents of the gravels are similar to those of the larger pit previously described.

The country on the right bank of the Bann opposite Kilrea is covered with mounds of gravelly drift similar to that just described, and on the flanks of Loan Hill (600 feet) between Portglenone and Hyndstown are many large mounds of drift between the 400- and the 500-foot contours; these are continued northwards to the neighbourhood of Rasharkin, and are of the nature of a lateral moraine.

North of Tully (668 feet O.D.) is a broad streamless channel at 520 feet, falling north-westwards, and striæ on the basalt close by run in the same direction. The boulders in this part of the area are chiefly of basalt, but there are also some from the Tyrone Axis.

The country south of Kilrea is distinctly morainic in character, and there are numerous small lakes and swamps, some of which occupy kettle-holes.

The Country north of Garvagh.

On the flanks of Gortnamoya Hill is a thin coating of brown gravelly drift containing basalt, schist, vein-quartz, Tyrone gabbro, and diorite; and on the col three-quarters of a mile south of Coolnasillagh Bridge similar material occurs in mounds which run north and south. There is no drainage-channel visible on this col, but thick peat is present.

The great lateral moraine which crosses the Agivey River is continued northwards by a series of detached drift-mounds of drumlinoid form, as, for instance, that at Hill of Boleram, 3 miles north-west of Garvagh, and that on which stands the Roman Catholic Chapel between Boleram and Lower Belraugh.

There are wide drainage-channels east and west of the latter hill, both being cut in basalt and falling northwards into the valley of the tributary of the Aghadowey River, which flows under Boleram Bridge. In the Aghadowey River itself, both above and below Shanlongford Bridge, are sections in brown boulder-clay and coarse gravels containing basalt, hornblende-schist, rotten mica-schist (common), vein-quartz, quartzite, red Carboniferous sandstone, red ironstone (Slieve Gallion), and red granite and hornblende-diorite from the Tyrone Axis. Many of these boulders are more than a foot long.

At Ringsend is a well-marked channel, at 360 feet O.D., cut in basalt and falling northwards, west of the Presbyterian Church, and a smaller one at 450 feet west of Priests Castle.

Immediately north of Cashel Bridge is a road-cutting in basalt without drift.

Three Nook Glen is another streamless channel cut in basalt and falling northwards; it is at a height of 380 feet. A similar channel is seen on the west of the road, having its intake at Leck Orange Hall, at 430 feet; and another at Lower Cam, half a mile farther west, at 460 feet, both falling northwards into the valley of the Shinny Water. A further channel at 480 feet, at Shinny Bridge, connects the valley of the Shinny Water with that of Roaring Burn, a tributary of the Macosquin River.

At The Pass, 5 miles west of Coleraine, is a shallow flat-floored valley connecting the valley of the Macosquin River with that of the Articlave River on the north. This is at a height of 370 feet, and is almost level. The floor is flat and swampy, and, although the present diminutive stream flows northwards, it is difficult to say whether the glacial drainage went northwards or southwards.

The col south of Windy Hill (820 feet O.D.) is cut by a deep channel, which connects the basin of the Macosquin River with that of Lough Foyle on the west. This channel, which is streamless, is about 35 feet deep, and has a flat floor: it is known as The Murder Hole. The bottom of the channel is practically level, and I am very doubtful as to the direction in which the glacial waters drained.

Half a mile away to the south is another col in a similar

situation. This is covered with a thick deposit of peat, and, if this were removed, the col would be below the level of The Murder Hole.

At Macosquin the drift is thin, the basalt coming to the surface in many places. In a thin gravel consisting chiefly of basalt I found a pebble of Ailsa Craig eurite, and one of gabbro from the Tyrone Axis.

A quarter of a mile north-east of Macosquin, near Coleraine, lies a mound of stratified gravel containing basalt, schist, quartzite, and a fine-grained granite, and 1 mile from Macosquin on the same road are two channels falling southwards. The Blackburn occupies the eastern one, flowing from an open peaty flat on the north, through the narrow valley at Blackburn Bridge, into the open valley of the Macosquin River.

In the sandpits near Coleraine Station the following rocks occur:—diorite, hornblende-granite, syenite, red granite, red quartz-porphyry, and mica-schist, all from the Tyrone Axis, also Ailsa Craig eurite, several varieties of pink granite (probably Scottish), and chalk and flint. The two last-named constituents are present in large quantity, and were derived from the neighbourhood of Portrush on the north.

Near Macfin Station, 5 miles south-east of Coleraine, and on the bank of the River Bann, is a gravel-pit in which the following section is exposed:—

	Thickness in feet.
Horizontally stratified yellow sands	6
Gravel..........	4
Fine sandy gravel, strongly current-bedded, with many pebbles of basalt (base not exposed) ...	15

The current-bedding dips in a direction varying from east to south-east.

In addition to the basalt which forms the bulk of the gravelly material, pink hornblende-granite, coarse red muscovite-granite, mica-schist, red sandstone, Silurian grit, vein-quartz, iron-ore (Tertiary), burnt flint, banded chalcedony, flint, and Ailsa-Craig eurite occur. All these rocks are such as could be derived from the north-east or north, there are no big boulders, and the materials are all water-borne.

The floor of the gravel-pit is some 50 feet above the level of the river, and forms part of a steep bank. The top of the deposit is flat, and defines a terrace which is continued on the opposite bank of the Bann. It should be noted that the valley of the Bann narrows suddenly at this point, half a mile below the railway viaduct, and that this narrowing coincides with the first appearance of a typically northern drift. I consider this terrace to be an outwash fan from the Scottish ice, at a time when the morainic deposits of Drummaquill, Ballymoney, and Armoy (previously described) were being laid down.

(b) The Valley of the River Main.

It will be convenient to begin the description of the deposits in this valley at its southern end, as the latest movement of the ice was from south to north.

It has already been pointed out that in the Randalstown-Cookstown Junction area the Tyrone rocks disappear from the drift about the line of the Midland Railway (main line), and in the district on the north they are confined to a narrow strip on the western side of the valley of the River Main. Thus, at Ahoghill, the boulders (though chiefly of the local basalt) include a few diorites and mica-schists from the Tyrone Axis.

On the old road between Galgorm and Ballymena, in the heaps of boulders picked from the neighbouring fields, only basalt and one fragment of chalk were found; and in a brickworks alongside the railway, half a mile south of Ballymena Station, in a very large collection of boulders I found only basalt, Silurian grit, vein-quartz, flint, and rhyolite.

North of Ballymena, and lying between the town and Berk Hill (506 feet), is an area covered by mounds of glacial gravel; in this are numerous extensive sand- and gravel-pits giving excellent opportunities for determining the origin of the materials. In none of these pits was I able to find any rocks from the Tyrone area.

A point of considerable interest is the transport of fragments of the local rhyolites of Quarrytown and Kirkinriola to the west of their outcrops, which must have been caused by the Scottish ice descending the valleys of the Braid and Clogh rivers.

As examples of these gravels, a description of the pits in two localities will suffice.

On the right of the main road from Ballymena to Ballymoney, and 2 miles from the former locality, are two large pits worked for sand and gravel. In the southernmost of the pits the material is strongly current-bedded, and the gravel, which is 12 feet thick and waterworn, rests upon the sand. There are beds and patches of extremely fine gravel consisting almost entirely of basaltic débris, but with numerous grains of white quartz in the sandy layers. The sand dips north-westwards at 5°, and is intersected by numerous small faults with throws varying from 3 to 4 inches. The coarse gravel consists chiefly of basalt, but also contains Tertiary quartz-rhyolite, bluish in colour (Kirkinriola type), flint, chalk, and Ailsa-Craig eurite.

In the northern pit the gravels are of considerably coarser texture, and contain many large boulders. They are roughly stratified, but not current-bedded. Here again basalt is predominant, the erratics being Tertiary rhyolite, flint, chalk, a basalt with porphyritic felspars, olivine-dolerite of Sliemish Mountain, and quartzite.

Nearer the main road is a deposit of stratified sand at a lower level than, and apparently passing beneath, the gravels.

At Drumbane, on the road between Ballymena and Clogh, are several pits in sand and gravel, with thin beds of red sandy boulder-clay. Many of the beds of sand are black, and consist of basaltic

débris. The gravels are brown, and rest upon the stratified sands. They contain chiefly basalt-boulders, many of which near the top of the section are very large, and smaller pieces of chalk, flint, red iron-ore (Tertiary), and chalcedony. The fluidal rhyolite of the Quarrytown type is plentiful. The gravel forms a mound, and the section is 15 feet deep.

In a large pit 500 yards south of the last-mentioned is a section of similar sand and gravel, in which the bedding is extremely irregular and contorted. It is current-bedded in parts, and the current-bedding dips in directions varying between west and north-west. There is a thin bed of buttery clay at the base of a mass of contorted sand. The clay shows slickensides, and apparently formed a gliding plane within the mass.

The surface of this area is undoubtedly morainic in character, bearing numerous irregular mounds, and a distinct moraine crosses the main road north of Moattown.

Between Ballymena and Broughshane the Braid River and its tributary the Devenagh Burn flow through an extensive flat consisting of basaltic gravels; while immediately above Broughshane the valley of the Braid is much contracted, owing to a moraine-like ridge which runs at right angles to the river, and separates the valley of the Devenagh Burn from that of the Creevamoy Burn.

In the neighbourhood of Buckna, and between that village and The Sheddings, are innumerable basalt-boulders and occasional fragments of chalk and flint, doubtless derived from Glenarm.

The north-western face of Sliemish Mountain bears several striated surfaces of basalt, the striæ indicating a flow in a south-westerly direction. Flint-pebbles occur up to 750 feet on the northern face of Sliemish.

Sliemish Mountain (1437 feet) is a steep-sided cone formed by a neck of olivine-dolerite, and is visible from nearly all the summits in Antrim, Londonderry, Tyrone, and Down. The view from the top is very striking and extensive, and from it can be made a study of the general trend of the drumlins and other mounds of glacial material in the surrounding country.

In the upper part of the Braid Valley the axes of the mounds trend from north-east to south-west, that is parallel with the valley; but in the neighbourhood of Broughshane and Ballymena they curve round towards the north-west. These directions are indicated, to some extent, by the contour-lines on the 1-inch map; but the feature is much more striking when viewed from the top of Sliemish.

In the valley of the Clogh Water and its tributaries the deposits are strikingly similar to those of the Braid Valley, and here again the axes of the mounds curve round north-westwards west of New-town Crommelin. In this case the northward movement of the ice at the foot of the valley is indicated by the overflow-channels on the spur of Slieverush. These are at 770, 750, and 530 feet respectively, and all fall northwards.

Near Drumadoon, a mile north of Clogh Mills, is a gravel-pit

excavated in a mound. Basalt and chalk appear to be the sole constituents of this deposit.

Running parallel to the railway along the valley of the River Main, from a point 1 mile south of Glarryford Station to 1 mile north of Dunloy Station, is a long ridge of gravel, which in places disappears below the surface of the bog for short intervals, but is otherwise continuous over a distance of 7 miles. Sections in the ridge reveal a coarse and very dirty brownish gravel, consisting for the greater part of basalt, but also containing a considerable quantity of rhyolite similar to that which occurs *in situ* at Clogh. This ridge is an esker, and occupies the line which one would expect a sub-glacial river to follow. It can be traced right up to the watershed at the head of the Main, and is continued northwards by an overflow-channel, deeply cut into the basalt, and falling into the valley of the northward-flowing Glenlough River.

Near Caldanagh Bridge, west of Dunloy, are many large boulders of the local basalt scattered over the country, and I found one erratic of epidiorite (Tyrone) and one of white Carboniferous sandstone similar to that of Slieve Gallion.

Mounds of drift tail off northwards from the end of this hill, and west of Tullaghans Burn is a long north-and-south ridge, which is the continuation of the lateral morainic accumulations between Portglenone and Hyndstown.

The watershed between the Main and its tributaries on the one hand, and the northward flowing streams on the other, crosses the railway about 3 miles north of Dunloy Station, and passes eastwards by Kendals Hill to the northern spur of Slievenahanaghan.

Between this watershed and the valley of the Bush River and the Breckagh Burn, running along the southern foot of the great Armoy moraine, is a series of big drift-mounds containing erratics from the south and occasional pebbles of Ailsa-Craig eurite.

VII. County Down.

The County of Down falls into four natural divisions: (*a*) a northern portion comprising the country around Bangor, Donaghadee, Mill Isle, Conlig, and Holywood; (*b*) the Ards Peninsula; (*c*) the Silurian uplands extending from Comber to Dundrum, and from Poyntzpass to Downpatrick and the mouth of Strangford Lough; and (*d*) the granitic mountains of Slieve Croob and the Mournes.

(*a*) The Northern Area.

This area is bounded on three sides by the sea, and on the south by the deep valley partly filled by Trias running from Belfast by way of Dundonald, Comber, and the head of Strangford Lough to Grey Abbey.

Along the line of the Belfast & County Down Railway from Holywood to Bangor are numerous sections in tough red boulder-

clay which contains erratics of Tertiary basalt, chalk, flint, and purple porphyrite, all from the Antrim coast on the north, also gneiss, Silurian grit, quartzite, schist, quartz-porphyry from Drumadoon Point and pitchstone from Corriegills (both in the Island of Arran), and Ailsa Craig eurite. There are also sections in similar material along the coast of Belfast Lough, near Helens Bay and Carnalea.

Between Bangor and Orlock Point the coastline is a low platform of Silurian rocks, apparently a raised-beach platform; but inland of this are low cliffs, capped in places by red boulder-clay. On the raised-beach platform are numerous boulders of dolerite and basalt, some of which are of considerable size, and pebbles of Ailsa Craig eurite are frequently met with.

In the country between the northern coast and the Dundonald Valley are many drumlins, the axes of which, for the greater part, lie north and south.

There is comparatively little of the sandy and gravelly material which forms so conspicuous a feature of the drifts of the Bann Valley and the Lough Neagh Basin; but there are mounds of sand and gravel at Bangor Castle, and south-east of it gravels also occur at Drumkirk and beneath the town of Newtownards.

In the Dundonald Valley are large quantities of sand and gravel disposed in irregular mounds. These are undoubtedly the product of the Scottish ice, as they contain a number of Scottish rocks (including that of Ailsa Craig).

Near the road-junction a mile east of Dundonald is a disused quarry in Triassic sandstone, covered by about 30 feet of red sandy drift consisting largely of reassorted Trias. The section is in the side of a mound of drift, and the following erratics are present:—basalt, flint, chalk, purple andesite, drusy granite from Arran, several varieties of decomposed granite with plentiful black mica (probably Scottish), and Ailsa Craig eurite. At the western end of this valley these deposits pass into a red sand with very few stones, similar to the Malone Sands of the Belfast Valley.

The country between Scrabo Hill and Comber is covered with drumlins of red sandy boulder-clay, containing Scottish erratics, the local Silurian grits, and the dolerites of Scrabo Hill. The last-named are present in great numbers, and are of large size and angular to subangular form.

(*b*) The Ards Peninsula and Strangford Lough.

The Ards Peninsula is a low-lying tract of land between Strangford Lough and the sea, and in no part reaches the 200-foot contour, except near Portaferry, where an isolated hill reaches 339 feet. The surface is covered by drumlins, containing Scottish rocks, with boulders of basalt and the local Silurian grits and slates.

In the area north-west of Grey Abbey are numerous boulders of the Scrabo Hill dolerite, and of these, one known as the

Butterlump, rests upon Triassic sandstone on the shore of Strangford Lough, about 4 miles south-east of Newtownards.

The peninsula was overridden by the Scottish ice, but does not appear to have been affected by the later glaciation from the west.

Strangford Lough occupies a position between the Ards Peninsula and the mainland of County Down, and lies in a very ancient valley which is, to some extent, filled by Trias; it appears, in part at least, to have been in existence since Carboniferous times.

At Castle Espie, about 3 miles south-east of Comber, there is a small outcrop of Carboniferous Limestone, and the ancient valley is otherwise Trias-filled.

The Triassic outcrop runs through from the Belfast valley by way of Dundonald and Scrabo Hill across the head of Strangford Lough to Grey Abbey, and probably it formerly extended down the Lough, but was removed by glacial erosion.

The Lough is for the greater part very shallow, only reaching depths of more than 100 feet in a few small closed areas, and the whole of its surface is broken by shallows and islands which are undoubtedly the tops of submerged (or partly submerged) drumlins, similar to those that characterize the surrounding country.

The striæ at Newtown Ards, Scrabo Hill, Ballygowan, Wood Island, near Ardmillan, and farther south on Slievenagriddle, near Kilcleaf, Killard Point, Bonfire Hill, and Gunns Island all point to a movement of ice down the Lough. This is confirmed by the transport of boulders of the peculiar red limestone of Castle Espie, which are to be found in quantity on the islands, in the country between Strangford and Downpatrick, and as far south as Killough.

The boulders and pebbles of Castle Espie limestone are accompanied by masses of the dolerite which forms the capping of Scrabo Hill. Some of these are of great size; for example, 'Sampson's Stone,' which lies south-east of Downpatrick, and is about 14 feet long; the 'Grey Rock,' at Scaddin near the mouth of the Quoyle River, which is slightly larger; and the 'Grey Stone,' north of Kearneys Town, which measures $18 \times 13 \times 8$ feet (+), part of it being below ground.

The area of the Ards Peninsula and Strangford Lough was covered throughout the Glacial Period by the Scottish ice, which moved over it from north to south, influenced little (if at all) by the pressure of the western ice.

The evidence of severe glacial erosion is to be found on all sides, and I look upon the Lough as the effect of that erosion on the soft Triassic rocks of the ancient valley.

(c) The Main Mass of the Silurian Uplands.

On entering any part of this district one is immediately struck by the extraordinarily hummocky character of the surface: drumlins and roches moutonnées follow one another in almost endless succession, giving the 'basket of eggs' appearance which

has been signalized by numerous writers as characteristic of County Down.

So complicated is the surface with its rounded hills, kettle-holes, and intervening strips of boggy land, that it is extremely difficult to interpret the glacial phenomena. There are so many streamless peat-filled valleys that it is, in most cases, impossible to distinguish between true glacial overflow-channels and the boggy strips between the drumlins.

One or two facts stand out, and give a clue to the direction of the ice-flow.

The eastern portion of the area, comprising the districts of Comber, Ardmillan, Saintfield, Ballynahinch, Crossgar, Killyleagh, Downpatrick, Killough, and Ardglass, was glaciated from north to south by the Scottish ice. This is indicated by the consistent direction of the striæ, and by the presence of northern erratics to the exclusion of Tyrone rocks.

The western portion, lying between the Belfast & County Down Railway from Comber to Crossgar and the Great Northern line from Belfast to Bannbridge, is much less easy of interpretation. The striations vary much in direction, and in some cases range through as much as 200° on the same surface of rock. That this crossing of striæ is due to varying direction of ice-movement, and not merely to the irregularities of the surface, is suggested by the general study of the drift-deposits.

Thus, in the country immediately south of Newtownbreda there are two distinct boulder-clays, a lower containing considerable quantities of chalk and an upper characterized by the predominance of slate and grit. Immediately south of this boulder-clay area Ordovician slates crop out at the surface, and bear striations varying in direction from north-west and south-east to north-east and south-west. A flow of ice from the north-west would bring chalk and basalt, while one from the north-east would pass over Ordovician and Triassic rocks.

Farther south the direction of striation becomes more regular, and, although varying through some 30°, is, generally speaking, from north-west to south-east. At the same time, a distinct change takes place in the character of the drift, which in this southern area contains numerous erratics from the Tyrone Axis. Thus at Ballygowan, 4 miles south-west of Hillsborough, the drift contains boulders of a quartz-porphyry which is intrusive locally in the Ordovician, hornblende-gneiss, syenite, red granite from the Tyrone Axis, Carboniferous sandstone (probably from the neighbourhood of Dungannon), also red sandstone (Trias), Silurian grit, basalt, and flint.

Between Dromore and Ballynahinch the country is covered with drumlins of boulder-clay, with some gravels in the hollows and occasionally on the tops of the hills. The erratics are mostly basalt, dolerite, rocks from the Tyrone Axis, and flint; but Scottish rocks also occur sparingly, and a small pebble of Ailsa-Craig eurite occasionally rewards a patient search.

Near Dromara is a shallow deposit of gravelly material containing much débris from the granitic area some 3 miles away to the south; but I consider this to be a post-Glacial wash brought down the valley of the Lagan in which it lies.

About 3 miles west of Ballynahinch, on the Dromara road, are several glaciated surfaces, upon which the striæ run in a direction about east 30° south; but, nearer Ballynahinch and clear of the Slieve Croob range, they incline more to the south. Thus at Rockvale, a mile east of the market-place, they run east 50° south, gradually conforming to the direction of those in the Downpatrick-Ardglass region farther east.

In the neighbourhood of Crossgar the rock is close to the surface, except where drumlins of boulder-clay with many local stones diversify the surface. The axes of the drumlins lie in a direction slightly west of north to slightly east of south.

Similar country is encountered on the road from Crossgar to Killyleagh; and on the shore of Strangford Lough, near the mouth of the Quoyle River, are cliffs of red boulder-clay 3 feet high. The clay contains many boulders of Silurian grit (some of which are striated), basalt, dolerite, Triassic sandstone, Castle Espie limestone, decomposed lamprophyre (local), mica-schist, chalk, flint, Cushendall porphyrite, and Old Red Sandstone.

Green Island, at the mouth of the Quoyle River, is the remains of a drumlin half of which has been cut away by the waves, and Dunnyneill Island farther north is of similar structure.

The country south of the Quoyle is partly covered by drift of a character similar to that which occurs between Crossgar and Killyleagh, and there are numerous striated surfaces all indicating a movement from slightly west of north.

A granitoid rock crops out at Slieve-na-griddle, about 4 miles east of Downpatrick, and a few boulders of this rock can be found on the surface of the Silurian country to the south.

At Killard Point, at the mouth of Strangford Lough, boulders of the following rocks were recorded:—local Silurian, Triassic sandstone, vein-quartz, dark red quartz-porphyry, quartzite, Castle-Espie limestone, porphyrite with epidote, flint (scarce), and Ailsa-Craig eurite.

Alongside the railway, about a mile north of Killough Station, are extensive excavations in a red laminated clay used for brick-making. The clay covers a considerable area of low ground lying among drumlins, and appears to be a Late Glacial accumulation of lacustrine origin.

On the beach at St. John's Point are many boulders of the local Silurian rocks and vein-quartz, and smaller numbers of basalt and porphyritic basalt from a local dyke, as also several rocks of the Tyrone type, including a coarse red-and-white granite and a hornblende-gabbro. The Slieve Croob granite also occurs.

The striations round Killough all indicate a movement of ice from the north-north-west, and this assumption is again borne out by the contents of the boulder-clay and gravels both inland and

on the coast of Corbet Head. Here is a very interesting deposit of calcreted gravel containing northern erratics (including Castle-Espie limestone and Ailsa Craig eurite). The calcretion is due to the very large quantity of Castle Espie limestone-boulders and pebbles, many of which have been in part dissolved and have provided the cementing material.

The occurrence of the Tyrone rocks and Slieve Croob granite on the shore of St. John's Point is probably due to beach-transport along the shores of Dundrum Bay, as these rocks have not been found in the Glacial deposits of the cliffs.

(*d*) The Granitic Areas of Slieve Croob and the Mourne Mountains.

The mountain Slieve Croob (1755 feet O.D.) is made up of indurated Silurian rocks on the northern edge of the granite intrusion which ranges from Castlewellan on the east to Slieve Gullion on the west, and forms a mass of high ground extending between those points, cut however by the valley of the Upper Bann and by the great trench which runs from the Lough Neagh basin to Carlingford Lough, by way of Scarva, Poyntzpass, Newry, and Warrenpoint.

I shall deal first with the country bounded on the north by a line running through Dromara and Gilford, and on the south by Newcastle, Hilltown, and Newry.

Although there is little direct evidence of this district having been overridden by the Scottish ice, the phenomena observed in the country immediately north and in the Mourne Mountains lead me to believe that such was the case; but so severe has been the subsequent glaciation by the western ice that almost all the materials of the existing drift have been derived from that direction, while all the striated surfaces are such as would be produced by an ice-sheet travelling from north-west to south-east.

At Lawrencetown near Bannbridge are several small exposures of red boulder-clay containing Tyrone rocks, together with Tertiary basalt, chalk, and flint; and between Lawrencetown and Scarva the country is covered by mounds of similar material, among which are several small lakes and peat-bogs which occupy hollows in the drift-deposits. The surface of the country is morainic in character.

There are few good exposures in this part, but about half a mile south of Scarva is a pit exposing some 30 feet of red boulder-clay, the base of which is not seen. This pit is excavated in the southern side of a mound, and at the southern end of the pit is a thin bed of sand. The clay, which is very stony, contains Silurian grit (local), basalt, flint, chalk, vein-quartz, Tyrone diorite and red granite, red quartz-porphyry, Carboniferous sandstone, Old Red Sandstone, and a large piece of silicified wood from the Lough-Neagh Clays, from all of which it will be seen that the material was clearly derived from the north-west.

Striations exposed during the building of the railway between Bannbridge and Dromore, and recorded by the officers of the Geological Survey, also indicate a movement from north-west to south-east.

Near Garvaghy, some 4 miles east of Bannbridge, are two large overflow-channels falling south-westwards and southwards respectively. They contain much peat and several boggy pools. The larger and northernmost of these channels is some 3 miles long, and its intake is at about 340 feet. I consider these to have been formed during the earlier northern glaciation, but their relationships are somewhat obscure.

On entering the hilly country along the northern edge of the granite intrusion we find the drift deposits to be much thinner than those in the low ground, and here the effects of the south-eastward movement are unmistakable. During the retreat temporary lakes were formed between the ice-front and the sides of the northward-falling valleys of the range, and their waters flowed southwards across the cols. cutting numerous channels. Some of the largest of these are between Deehommed Mountain and Slievenaboley, between Slievenaboley and Cratlieve, and between Cratlieve and Slieve Croob, where there are two parallel channels. There is also a channel falling south-eastwards between Slievenisky, the southern spur of Slieve Croob, and Slievegarren.

The larger channels of this range were doubtless produced during the northern glaciation, and again occupied by streams during the glaciation from the west.

In this area are many boulders of local granite in the drift, also numerous erratics of Silurian grits and slates, and pebbles of flint derived from the north-west. I have been unable to find the igneous rocks of the Tyrone Axis; but, in such a profusion of granitic débris as occurs here, they would, even if present, be very difficult of detection.

Southward from Slieve Croob to the neighbourhood of Lough Island Reavy runs a ridge of hills, the craggy summits of which reach heights of from 700 to 1000 feet. This ridge lay athwart the path of the western ice, and on all hands are to be seen signs of the severe abrasion to which the rocks were subjected during its passage. Thus on Curlets Mountain, which consists in part of granite, and in part of highly metamorphosed Silurian rocks, the former is worn into rounded bosses, and the latter are extensively striated.

North of Curlets Mountain lies a broad valley, which cuts through the range at a level of about 330 feet, and has evidently carried a much larger stream than that which occupies it at present. It falls eastwards, and carries the railway between Leitrim Station and Castlewellan.

South of Curlets Mountain the ridge is cut by numerous small notches, which were produced when the ice stood against the western side of the ridge, but was no longer able to overtop it. Several of these notches drain into the hollow now occupied by Castlewellan Lake.

A much larger and more definite channel runs in a north-easterly direction from the eastern end of Lough Island Reavy, by way of Altnadua Lough, to the valley of the Burren River near Castlewellan. The stream which now flows through this valley is only 3 feet wide, and is almost choked with grass and other vegetation, whereas the floor of the valley is wide and swampy and is nearly level, though with a slight fall towards the north-east.

The valley of the Burren River below the point where this channel enters it is very wide, has a flat floor, and is out of all proportion to the size of the river.

The comparatively low-lying country between Lough Island Reavy and Rathfriland, and thence onwards to the Newry Valley, is covered by mounds of drift, among which are numerous small lakes and peat-bogs occupying hollows in the drift.

The Mourne Mountains.

Under this head will be described that part of County Down which lies south of the Castlewellan-Hilltown-Newry road.

An examination of a contoured map will show that south of that portion of the road which lies between Hilltown and Newry is a triangular hilly area based upon the road, having its apex at the head of Carlingford Lough, bounded on the south-west by the steep mountains of the Carlingford Range, and on the south-east by the Mourne Mountains.

The evidence of the extreme severity of the glaciation to which this triangle has been subjected is to be seen on every hand, in the general form of the country, in the frequency of roches moutonnées and striated surfaces, and in the enormous overflow-channels by which the country is intersected (see map, fig. 7, p. 406).

The interpretation of the glacial phenomena of this triangle is a comparatively simple matter, for, although it was covered first by the Scottish ice and later by that from the north-west, the lower layers, at least, of both these sheets were constrained by the form of the ground to flow southwards, and to find escape through the narrow opening between the Carlingford and Mourne Mountains, now occupied by the fiord of Carlingford Lough.

Carlingford Lough, in fact, owes its existence very largely to the erosive power of the glacier; and it is a point of great significance that the narrowest portion of the Lough, where it cuts through the mountain-barrier, has the most precipitous sides and is of greater depth than any other part.

Running down the centre of the Lough from opposite Killowen to a point 1 mile north of Greenore, is a deep channel round which the 5-fathom line forms a closed contour. In the narrowest part of the valley, where the ice-scour was necessarily greatest, the bottom of this trough descends below the 15-fathom line, a depth which is not again reached within 5 miles of the coast (see fig. 8, p. 408).

From Greenore to the actual mouth of the Lough is another

closed deep of very irregular form, which in places reaches the 10-fathom line; but, between this and the open sea, is an area about a mile wide which is less than 5 fathoms deep. That this is not due to the silting-up of the mouth of the Lough, or to its obstruction by morainic material, is indicated by the presence of numerous reefs and islands of Carboniferous Limestone between Greenore and the sea, from which it would appear that the Lough occupies a rock-basin.

An examination of the direction of the striæ on the rock-surfaces bordering the Lough shows that the ice, after passing the narrows, fanned out over the more open country on the south, flowing over Greenore and Whitestown on the one hand, and towards Kilkeel on the other.

The drifts of the triangle contain great numbers of boulders of the Newry granite, and a smaller quantity of Silurian débris, while basalt and flint from the north are not uncommon.

The glacial drainage-channels which form so conspicuous a feature in this area must now receive attention. The largest of these is over 20 miles long, and connects the low-lying swampy area south of Portadown with the head of Carlingford Lough at Warrenpoint.

The country immediately south of Portadown is an almost level swampy plain, rapidly narrowing about 2 miles south of the town to form a deep flat-floored valley, through which pass the River Bann, the canal, and the Great Northern Railway. The Bann enters this valley near Gilford, and flows northwards through Portadown into Lough Neagh, the fall being very slight and the stream sluggish. Near the point where the Bann enters the valley, but in this case from the south-west, another stream, the Cusher River, flows in, and also runs northwards, joining the Bann near Portadown.

From Gilford southwards by Scarva to Poyntzpass, the valley-floor is streamless and almost level; but near the latter village small streams enter from both sides, and flow southwards. The valley continues to fall southwards, and passes through Jerrettspass and Newry to Warrenpoint, the part between the two last-named towns being at sea-level and carrying the Newry Ship Canal.

The whole of this valley is below the 100-foot contour, and is altogether out of proportion to the drainage which it carries.

The Newry River, after an extremely erratic course, falls into the great valley about 3 miles above the town of Newry, but between that point and Gilford the channel is practically streamless. The origin of this valley I attribute to the drainage from the Lough Neagh Basin, which during the period of the advance of the Scottish ice, must have taken this course.

The valley is deeply cut in the solid rocks, and can be seen to be somewhat encumbered by the drift of the western ice by which it was crossed. The deposits of this ice almost obliterated the northern part of the channel, which however was partly re-excavated

by the drainage of Lough Neagh during the retreat of the western ice, while the Belfast Valley and that of the Lower Bann near Castlerock were still closed by the Scottish ice.

The problem of the pre-Glacial drainage of the Lough Neagh Basin is an extremely interesting one; but, before anything definite can be said on this subject, or on the cognate one of the origin of the existing drainage-system, a much closer study of the sub-drift contours than is at present possible must be made.

To return now to the drainage-channels of the Newry-Hilltown-Warrenpoint triangle. There is a very large flat-floored valley running parallel to, and about a mile east of, the Newry Valley. It contains Greenan Lough, and several other small lakes and swamps. The watershed in this valley is at about 110 feet, and its northern end is crossed at right angles by the Newry River at a level of 105 feet. At its southern end the channel deeply notches the 100-foot contour, and enters the Newry Valley opposite Narrow Water Castle.

Another large parallel channel at a higher level (320 feet) runs between Bullock Hill and the southern spur of Craignamona. It contains Milltown Lough, falls towards the south, and is streamless in its upper part.

Other channels occur on the north-western flank of Craignamona at 590 feet, and between Slieveacarnano and Ballyvally Mountain at 612 feet: both these fall southwards.

The two great parallel valleys (through which pass the two roads from Hilltown to Rostrevor) lying between Slieveroosley and Corlieve Mountain, and between the latter and Tievedockeragh respectively, and cutting through the watersheds, are much encumbered by drift and peat, but must have carried great volumes of water from the Hilltown area southwards to Carlingford Lough.

The Mourne Mountains consist, for the greater part, of granite of Tertiary age, although the summits of several of the highest peaks in the western portion are capped by masses of altered Silurian strata—the relics of the cover of the granitic laccolite.

These mountains form a detached group, which stood in the track of the Scottish ice that swept over County Down, and were to a considerable extent overwhelmed by it. Striæ occur up to and slightly above the 1500-foot contour on Pigeon Rock Mountain, and the plateau of Silurian rocks which forms the summit of Slievemuckamore (1837 feet O.D.) is littered by thousands of granite-boulders carried from at least 250 feet below.

Whether the higher summits, such as Slieve Donard (2796 feet) and Slieve Bignian (2449 feet), were covered by ice is largely a matter of conjecture; but their rounded outlines, and the fact that Snaefell in the Isle of Man (2062 feet) was overridden, make it reasonable to suppose that such was the case.

Running westwards from Slieve Donard is a line of peaks forming the northern rampart of the group—Slieve Commedagh (2812 feet),

Slievenaglogh, Slieve Bearnagh (2394 feet), Slieve Meelmore, and others; and that this rampart was overridden from the north is shown by the enormous accumulations of glacial deposits in the Silent Valley and the valley of the Annalong River on the south. These deposits consist very largely of granitic débris, but occasional boulders of Silurian grits and altered slates also occur.

The mountain-tract is divided into two portions by the pass which carries the road from Hilltown to Kilkeel by way of the Deers Meadow, and the fact that the northern ice flowed over this pass is indicated by the striated surfaces and by the transport of thousands of boulders of the altered Silurian rocks (banded hornstones, etc.) of the Deers Meadow southwards through the narrow valley between Slievemuck and Pigeon Rock Mountain. The highest point of the pass is 1225 feet; but that the ice stood at a much higher level than this is shown by the striæ on the southern spur of Pigeon Rock Mountain at 1500 feet, and the granite-boulders on the summit of Slievemoughanmore already mentioned.

To what extent the Mourne Mountains were overridden by the subsequent western glaciation is a much more difficult matter to decide. On Castle Bog, between Tievedockeragh and Eagle Mountain, I found several pebbles of flint in sandy drift beneath peat at about 1100 feet; but these might obviously have been carried by either the Scottish or the western ice, though a well-marked overflow-channel known as The Windy Gap, at about 1300 feet (between Slievemoughanmore and Eagle Mountain, and falling south-eastwards), might be taken as an indication of an ice-movement from the north-west.

About 4 miles south-west of The Windy Gap is another overflow-channel on the northern flank of Slievemee at about 1200 feet, and this also falls in a south-easterly direction; while on Finlievemore at 1300 feet are striæ pointing south-eastwards.

Near the summit of the col south of Slievemee are two parallel crescentic moraines at a height of 1000 feet. They are convex towards the south-east, and were doubtless the product of an ice-lobe pushing its way over the col from the north-west.

It is thus clearly shown that ice passed over the south-western part of the Mourne Mountains from a north-westerly direction; but it must be borne in mind that this may have been a portion of the Scottish flow escaping from the enormous pressures in the rapidly-narrowing triangular area on the west which has already been described.

I have been unable to find any undoubted Tyrone rocks at high levels in the Mourne Mountains, and, until such are forthcoming, the invasion of the group by the western ice must be a matter of conjecture.

That the ice from the Tyrone area flowed along the northern face of the Mourne Mountains is indicated by the direction of the striæ at 500 feet O.D. on the north side of Loughaulea Hill, at 700 feet at Fofanny Plantation on the southern flank of Craigalusta and on the northern slope of Slievenaman, at 650 feet on

Tullyree Hill, and at 750 feet on Slievenabrook, all of which show evidence of a movement from west to east. This movement is confirmed by the transport of large numbers of boulders of quartz-porphyry from the great dyke which runs from Craigalustra to Hilltown, into the country round Bryansford.

The strip of Silurian country south of the granite mountains is deeply covered with drift, of which there are good sections along the coast.

Striations and moraine ridges show a coastwise movement of ice in an easterly direction from the mouth of Carlingford Lough. This, as has already been stated, was due to the fanning-out of the ice on its escape from the narrows between the Mourne and Carlingford Mountains, doubtless influenced largely as regards direction by the eastward thrust of the ice from the country north of Dundalk presently to be considered.

The gravels in the southern valleys of the Mourne Mountains are often of great thickness, and consist principally of granite. They are disposed in moraine-like ridges in many parts.

VIII. The Carlingford Mountains and the Slieve Gullion Area (see map, fig. 7, p. 406).

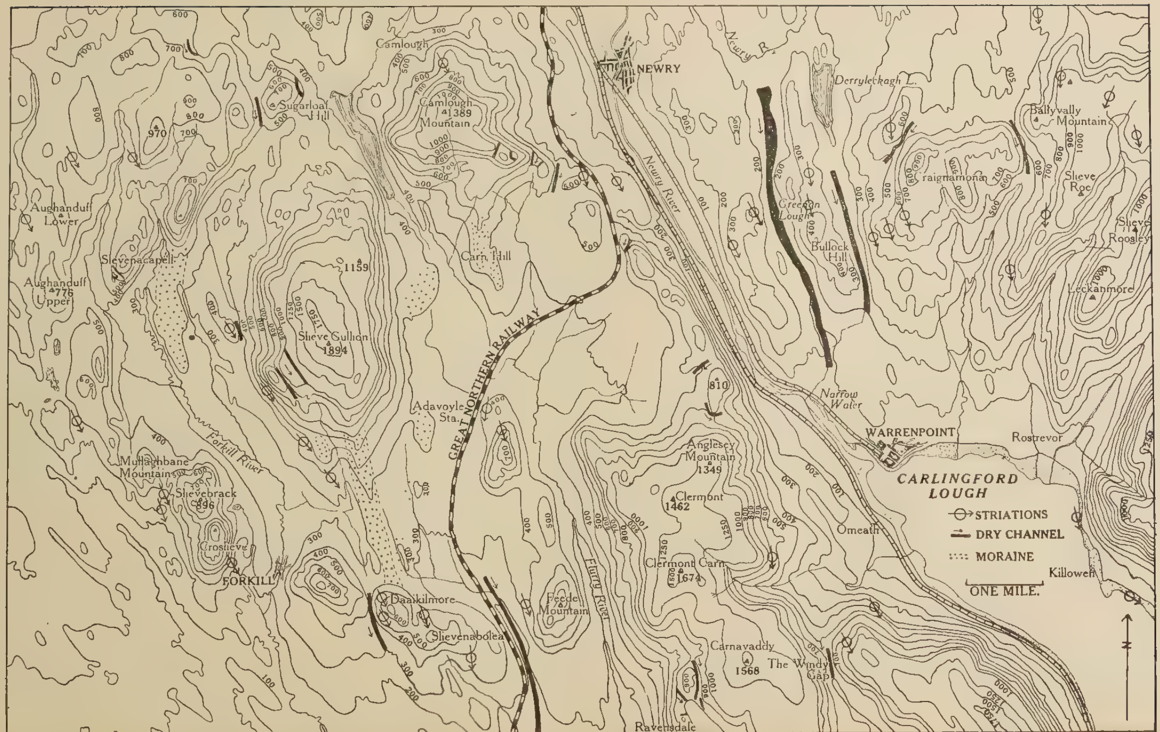
In the portion of this region that lies immediately north of Slieve Gullion (which must not be confused with Slieve Gallion in Tyrone) and Camlough Mountain the roches moutonnées and striated surfaces indicate an ice-movement from west of north. These occur near Bessbrook at 450 feet O.D., in the townland of Eshwary at 560 feet, on the northern flank of Camlough Mountain at a little over 700 feet, a quarter of a mile north-west of Davitts Cross Roads at 700 feet, and in two places near Aughanduff Lower Mountain at 700 and 630 feet respectively.

North-west of this area the country from Beleek by Ewarts Cross-Roads to Jerrettspass is deeply covered with drift, both boulder-clay and gravels, containing a profusion of boulders of Silurian rocks, together with considerable numbers from the Tyrone Axis; and near Jerrettspass are roches moutonnées at altitudes of 250 and 450 feet respectively, also indicating a movement from west of north.

The drift occurs in mounds, some of which are drumlins: as, for example, those at Tullyah Hill and Carrowbane near Belleek; others are more irregular in form, and probably morainic.

In a large excavation midway between Newry and Camlough is an exposure of decomposed granite, formerly worked for gravel, covered by 15 feet of buff-coloured boulder-clay which contains much local granite, with smaller quantities of Silurian grit and slate, both showing striæ, also quartzite, flint, Tertiary basalt, vein-quartz, and red granite from the Tyrone Axis. The pit is in the side of one of the mounds, and there is little or no drift in the spaces between them, the granite and granite-wash coming to the surface.

Fig. 7. [For '1568' on Carnavaddy, read '1508'.]



The eastern spur of Camlough Mountain, known as Ballymacdermot, is cut by five dry channels at 920, 910 (in and out), 650, and 630 feet respectively.

Between the village of Camlough and the reservoir the surface is largely granite, but boulder-clay similar to that just described occurs in patches; and in the narrow part of the reservoir valley at 500 feet is a cutting which shows rotten granite, covered by about 3 feet of boulder-clay containing local rocks only. With the exception of this small patch, the sides of the valley appear to be free from drift; but, on the west side of the reservoir, is a long ridge of drift, running from north-west to south-east through Aghmakane.

On the eastern flank of Sugarloaf Hill is a dry channel falling southwards at 800 feet, and another between Sugarloaf Hill and Courtney Mountain at 550 feet.

The south-western spur of Slievenacappel is cut by three parallel dry channels, all falling south-eastwards between the 600- and 700-foot contours.

The mountain of Slieve Gullion (1894 feet O.D.) stands in the centre of a great amphitheatre, and is separated from the walls of the basin by valleys upwards of a mile wide. On the western flanks of Slieve Gullion roches moutonnées occur at 400 feet, a striated surface at 600 feet, and dry channels at 950 feet and 1200 feet respectively show that it was glaciated at least up to the last-mentioned level.

The valley that surrounds Slieve Gullion on the north-west, west, and south-west, drained by the Forkill River, shows much drift which contains mostly local and Silurian rocks. This drift is arranged for the greater part in long mounds, which have their axes north and south.

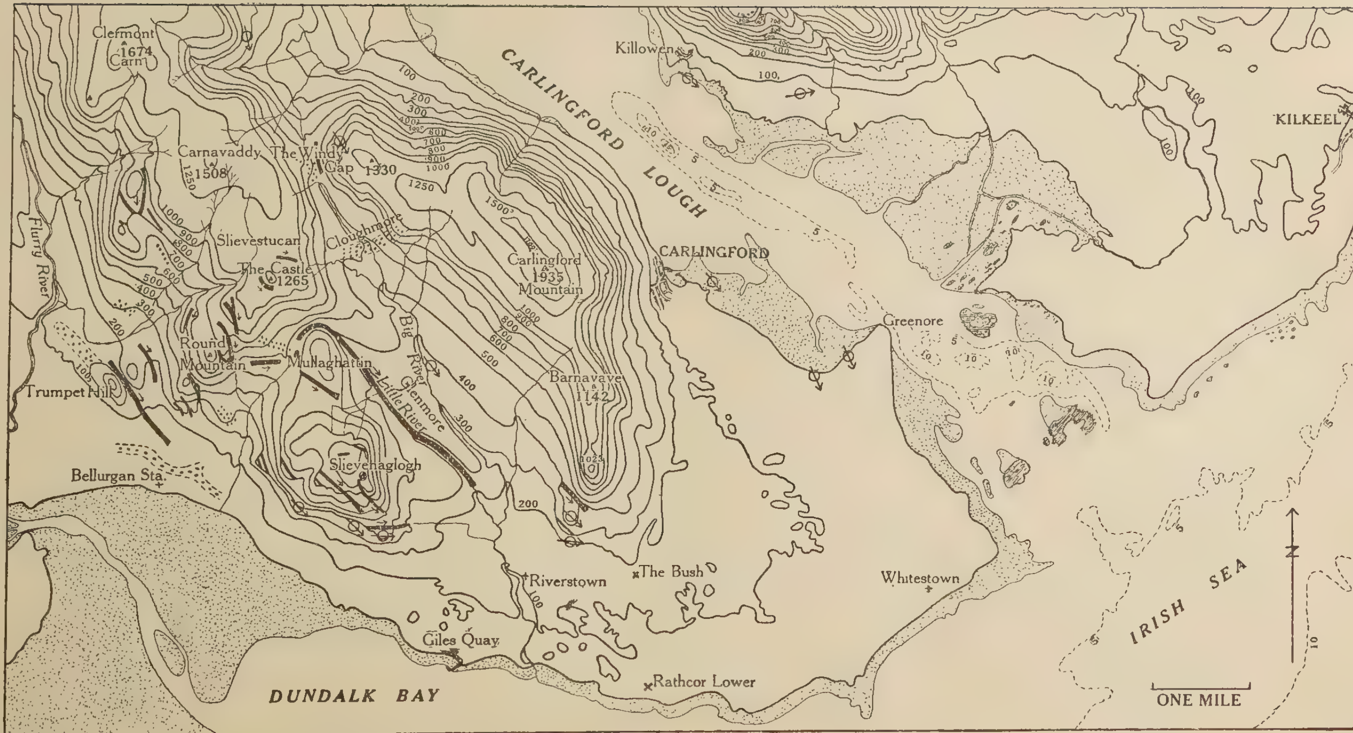
East of the mountain is the great basin of Adavoyle, at a level of between 300 and 400 feet, through which runs the main line of the Great Northern Railway from Dublin to Belfast. Much of the surface of the basin is covered by peat; but drift-mounds frequently show above its surface, and there are kettle-holes of considerable dimensions near Drumintee and at Ballynamona.

The basin is at present drained by three streams, the largest of which is the Flurry River, flowing southwards through Ravensdale. A smaller stream also flows southwards through the valley which carries the railway, and the northern portion drains northwards into Camlough Reservoir.

The southern rim of the amphitheatre shows many roches moutonnées and striated surfaces, all indicating a southward flow, and is cut by four large gaps. The westernmost of these is at Forkill (230 feet), and is occupied by the Forkill River. It has the contours of a normal valley, but is very large in comparison with the size of the stream.

The second is at a height of 380 feet, and lies half a mile north-east of Forkill House. This is a deep gorge-like valley cutting through the wall of the amphitheatre, and flanked by

Fig. 8.



CARLINGFORD LOUGH
CARLINGFORD
Killowen
KILKEEL
Greenore
Whitestown
IRISH SEA
ONE MILE
Clermont
1674
Carn
Carnavaddy
1508
The Windy Gap
1330
Slievestucan
The Castle
1265
Cloughmore
Carlingford
1935
Mountain
Barnavave
1142
Round Mountain
Mullaghattin
Big River
Glenmore
Little River
Slievenaglogh
Trumpet Hill
Flurry River
Bellurgan Sta.
Riverstown
The Bush
Giles Quay
Rathcor Lower
DUNDALK BAY

ancient watch-towers. The rocks on the east side are strongly moutonnés. At the southern end of the gorge is a drift-plateau fringing the mountains, and the channel is continued across this for nearly a mile. The channel is now almost streamless.

The third gap is that between Slievenabolea and Feede Mountain. It cuts the 200-foot contour, and is thus lower than those previously mentioned. It is a very large channel with a broad flat floor, and must have carried a powerful stream, at one stage draining the greater part of the amphitheatre. The existing stream is very small, and quite inadequate for the cutting of so large a valley.

The fourth channel is Ravensdale, already mentioned as being occupied by the Flurry River. The upper end of the narrow portion of the dale is at Flurrybridge, at 320 feet above sea-level.

This completes the circuit of the Slieve Gullion amphitheatre, and there remains for description only the mountainous tract of country between Ravensdale and Carlingford Lough.

This area consists of two main masses, western and eastern, separated one from the other by the col known as The Windy Gap, above Omeath and Glenmore, the valley occupied by the Big River and the Little River, leading southwards from The Windy Gap to the sea (see maps, figs. 7 & 8, pp. 406 & 408).

The western mass includes Anglesey Mountain (1549 feet O.D.), Clermont (1462 feet), Clermont Carn (1674 feet), Carnavaddy (1508 feet), The Castle (1265 feet), and Slievenaglogh (1024 feet); the eastern includes the long ridge of Carlingford Mountain (1935 feet) and Barnavave (1142 feet).

Anglesey Mountain is prolonged northwards by a long ridge which separates the Newry Valley from the Adavoyle Basin. This ridge falls very steeply towards the Newry Valley on the east, but much more gently on the west. It is cut through by several dry channels, all falling westwards, at levels between 300 and 600 feet.

Striations near Monument show a movement down the valley, and the ridge now under consideration forms the western boundary of the Newry-Hilltown-Warrenpoint triangle defined on p. 401.

At the southern end of the ridge, a mile north-east of Clontigora, is a channel at 650 feet falling westwards: that is, from the Newry Valley towards the head of Ravensdale; and a quarter of a mile south of the summit marked 810, another channel just below 700 feet falls first southwards, and then eastwards. There are considerable accumulations of drift here, and the surface is very irregular and moraine-like.

There are several small streamless notches, all falling south-eastwards, on the shoulder of Anglesey Mountain between the levels of 700 and 900 feet.

In the course of a stream which flows from Clermont to the Lough, north of Omeath Park, are several deep sections in pinkish-buff boulder-clay crowded with big boulders of granite and quartz-

porphyry, both of which rocks are local, also striated Silurian grit, Tertiary basalt, and flint. The material is distinctly morainic in character, and extends up to the 900-foot contour. The country below this, right down to the Lough at Omeath village, is also covered with similar material disposed in long flat mounds. Striæ on the hillside west of Omeath point almost due south.

The deep embayment in the eastern side of Clermont Carn contains similar drift (in which there are sections 30 feet deep), forming a terrace at a level of 600 feet.

In The Windy Gap is a frontal moraine of considerable dimensions, through which there is an ill-defined streamless channel falling southwards. The moraine contains many angular blocks of granite, quartz-porphyry, and dolerite, all of which occur *in situ* in the area immediately on the north.

Immediately south of The Windy Gap is a shallow lake, about half a mile long, at a level of 600 feet. It is held up by a frontal moraine which crosses the valley at Cloughmore. Below this point the valley, sometimes called Glenmore, contains great quantities of drift exhibiting a roughly terraced arrangement; but there are no further frontal moraines, unless the accumulations of gravelly materials at Riverstown, which will be mentioned later, can be so described.

The drift-level on the western slopes of Carlingford Mountain is well defined by the limit of cultivation, which is at about 900 feet above O.D.; but this does not mark the upper limit of the ice, as some erratics occur on the summit of the mountain.

Striæ on an inlier of Silurian rocks in the centre of Glenmore, at about 380 feet, show that the ice which crossed The Windy Gap extended at least thus far southwards, and there seems little doubt that it reached the foot of the valley and passed out to sea.

The western face of Carnavaddy is heavily drift-covered in the townlands of Anaverna and Doolargy, and at a height of 600 feet a stream cuts through a great lateral moraine consisting of brown sandy clay, with many subangular blocks of granite. The thickest part of the moraine appears to be at the forking of the two streams, where there is a section 60 feet deep with the stream still flowing on drift. Most of the granite-boulders are in the lower part of the section.

Farther up stream above the moraine is a plateau of drift 200 yards wide, with another moraine roughly parallel to the first on its upper side. The drift of the terrace is stratified, and was deposited in the waters of a lake which stood at a level of 870 feet, and overflowed by a channel between Carrabane and Carnavaddy. This channel discharged its waters into another lake which occupied the valleys on the side of Slievestucan, in the townland of Ballymakellet, and the waters overflowing from this cut a series of channels in the spur which runs south-westward from the summit of The Castle, by way of The Round Mountain to Bellurgan House. These channels will be described later.

The broad valley occupied by the various streams which unite to

flow under Ballymakellet Bridge have cut deeply into, and in some places through, the drift. The stream which rises south-east of the summit of Carnavaddy and flows on the west of Slievestucan exposes sections in stratified gravelly drift at least 40 feet thick, at an altitude of 900 feet. A rough terrace of drift can also be traced round the shoulder of Slievestucan to the valley of the stream which, rising near the source of that last mentioned, passes round the east side of Slievestucan, between that hill and The Castle, and is known in various parts of its course as Shrufawnasheskon and Altboy. In this latter stream, extending between the 700- and 900-foot contours, is a drift-section upwards of 100 feet in height, forming a great scaur above the stream, and called Spelleekboy. This drift is roughly stratified, and extends up the hillside beyond the level of the terrace on the shoulder of The Castle to a height of about 1200 feet.

Both the streams above mentioned cut into the drift in many parts of their courses, from the 700-foot level to the bridge at Ballymakellet; and the sections revealed indicate the existence of several parallel lateral moraines, with intervening flats of stratified drift. These deposits were formed in the waters of a lake held up between the margin of the ice and the hillside.

At the period of maximum glaciation the mountains were wholly covered; but, as the ice-level decreased, the lake took various forms at various levels, and the history of these changes can be worked out by a study of the fine series of dry channels on the spur of The Round Mountain.

The highest of these is east of The Castle at a level of 1100 feet, and discharges direct into Glenmore below the Cloughmore moraine. The channel is small and ill-defined, and was formed by the drainage from the glacier before the ice had dwindled sufficiently to allow of the production of a lake.

A similar origin may be postulated for the channel at about the same level, on the western slope of The Castle.

The first of the lake overflows is at 950 feet, cuts through the south-western spur of The Castle, and falls southwards. It is broad and shallow but well marked, and is partly occupied by a swamp called Moneyboy. The second of this series is at 900 feet: it is similar to the last-mentioned, which it eventually joins, and produces a deepening of the lower portion.

This is followed by a small channel at about 810 feet which must have been of a very temporary nature, being early rendered inactive by the opening of the col between The Round Mountain and the spur of The Castle.

East of The Round Mountain, and cutting the col last mentioned at about 720 feet, is a group of deep overflow-channels cut in hard dolerite. They unite to form a dark gloomy gorge known as The Cellar, which opens into the Jenkinstown valley. The waters of this channel drained eventually by way of the great Mullaghattin channel into Glenmore (see p. 412). The head of the main channel of the group is occupied by a swamp called Loughlyboy,

and contains two small lakes the overflow from which, a mere trickle, is rapidly lost in the talus in The Cellar, and is the only drainage now passing this way.

On the northern spur of The Round Mountain, at a level of 650 feet, is a well-marked channel 30 feet deep, which carried the drainage through the spur to the western side of The Round Mountain, thus lowering the level of the Ballymakellet Lake, and rendering The Cellar channels inoperative. The drainage from this channel, and later, the direct overflow from the lake, cut an enormous compound channel through the western flank of The Round Mountain, the eastern and original intake being at 490 feet, and the western and later one at 460 feet. The lower end of the combined channel cuts the 200-foot contour.

By the time that this channel had been opened the ice had retreated from the southern flank of Slievenaglogh, and the lake in the Jenkinstown valley (see below) had ceased to exist. This is proved by the fact that this channel, and also all the later channels next described, drained into the open country south of the mountains, and thus into the Irish Sea.

The Round Mountain throws out a spur towards the south-east, and this is cut by two very large 'gash-channels' at 410 and 350 feet respectively. These channels reach, but do not cut through the crest of the spur, and are similar in origin to those described on p. 411.

The lowest of the overflows of the Ballymakellet Lake is between Trumpet Hill and the hill (300 feet) east of it. The channel is very large, being 200 feet deep, and must have been operative for a long time. Its period of activity continued until the glacier had retreated beyond the northern end of Trumpet Hill, as the channel can be followed in the low country below the 100-foot contour to the neighbourhood of the moraines near Bellurgan Station.

The channels above described as lying between The Castle and The Round Mountain drained into the valley between The Round Mountain and Slievenaglogh, which was also occupied by the waters of a lake. This, which may be called the Jenkinstown Lake, from the name of the townland in which it occurred, drained over the col at the head of the valley, cutting an enormous channel which carried its waters into Glenmore. This Mullaghattin channel is at a level of about 550 feet, at the watershed between the southward flowing stream and the headwaters of the Little River which now occupy the channel. North of Mullaghattin the channel is cut deeply into the solid rock; but, after turning south-eastwards into Glenmore, it continues as a definite wide channel in the drifts of that valley, down to a level of 200 feet.

It will thus be seen that the western, or Tyrone, ice which produced the lake phenomena described above, must still have stood against the southern shoulder of Slievenaglogh up to about 600 feet, so as to impound the waters of the Jenkinstown Lake, at a time when the southern spur of Barnavave was clear of ice down

to the 200-foot level, and the northern ice from The Windy Gap no longer penetrated Glenmore below the Cloughmore moraine.

The Jenkinstown valley is largely encumbered with drift, arranged in roughly parallel ridges, which obviously were lateral moraines of the western ice produced during the various stages of its shrinkage.

There are numerous overflow-channels on the southern face of Slievenaglogh; but they are of small size, and appear to have carried small streams from the edge of the ice rather than the overflow of a lake. At the foot of the slope near Rockmarshall House striæ point south-eastwards, and at Clogh Patrick, a mile farther east, they run from west to east. Near The Bush Station are striæ on the spur of Barnavave, pointing only a few degrees south of east, showing that the western ice was pressed closely against the ends of these hills.

With regard to Carlingford Mountain there is little to say, except that on the summit numerous small erratics of Silurian grit occur. These are at least 500 feet above the parent outcrop, and show that the mountain was completely overridden by ice from the north.

South of the mountains, and between them and the sea, is a strip of slightly undulating land, varying from half a mile to 3 miles in width and lying below the 200-foot contour. It consists entirely of glacial deposits, boulder-clay below and gravel above.

In the neighbourhood of Bellurgan Station, on the Dundalk, Newry, & Greenore Railway, is a series of lateral moraines having a general trend from west-north-west to east-south-east. These moraines form several parallel ridges, and consist of brownish and somewhat clayey gravel, containing boulders and pebbles of Silurian and igneous rocks from the neighbouring hills, from Slieve Gullion, and from the Tyrone Axis.

A section in the morainic gravels close to Bellurgan Station yielded several varieties of granite, andesites, and Silurian grits, all derivable from the country immediately to the north-west, Carboniferous Limestone (local), basalt, white quartzite, and red quartz-porphyry.

Immediately south of Rockmarshall House, at the point where the road passes beneath the railway, is a pit excavated in a very sandy brown clay, in which no bedding is apparent. The boulders are similar to those found at Bellurgan Station, and the pit is in one of a series of morainic mounds which occur on both sides of the railway.

The two small lakes, Lough Anmoney and Lough Anmore, between the railway and the sea, occupy closed hollows or kettle-holes, Lough Anmore lying in a hollow enclosed by the 50-foot contour.

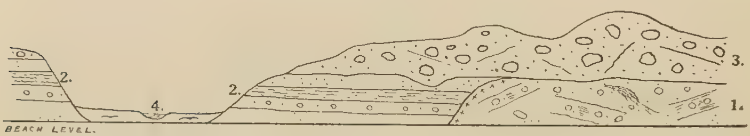
Near the viaduct at Riverstown the river cuts through the drift-plateau, and exposes a section of a moraine with a terrace of stratified gravel on its upper, northern, side. The bedding in the moraine is confused; but that in the terrace is horizontal and, with

the exception of certain current-bedded portions, quite regular. The erratics are similar to those found at Bellurgan and Rockmarshall House.

In another section, between the railway and road-bridges at Riverstown, boulders of basalt are extremely common in the lower part of the section, while rocks from the north-west predominate higher up. The section was partly grassed over and covered by slips and talus, consequently it was impossible to ascertain without considerable excavation whether there is a definite line of demarcation between the basaltic drift and that lying above it. In the light of the relationship of the beds in the cliff-sections shortly to be described, I am inclined to ascribe the basaltic drift to earlier ice, probably Scottish, which came by way of the Newry Valley, over The Windy Gap and so down Glenmore, and the upper deposit to the later glacier which came round the western side of the hills by way of Bellurgan.

Between Giles Quay and Rathcor Lower the beach is bounded

Fig. 9.—*Section in the sea-cliff at the mouth of the river below Riverstown.*



1 = Older moraine. 2 = Stratified sands and gravels.
3 = Newer moraine. 4 = River.

by cliffs of boulder-clay, sands, and gravels, which occasionally reach a height of 50 feet.

On the eastern side of the mouth of the river at Riverstown are exposures of strongly current-bedded sands and gravels containing Silurian grit, Carboniferous Limestone, granophyre, diorite, and a few small pebbles of Tertiary basalt, all of which (with the exception of the basalt) are local. The current-bedding dips southwards at about 20°. Resting upon these gravels are mounds of brown boulder-clay containing large boulders. The gravels just described extend for about 100 yards eastwards along the sea-cliff, where the section illustrated in fig. 9 (which clearly indicates their relationship to the other deposits) is seen.

Between the fishermen's cottages and the end of the road at Rathcor Lower is a continuous section, a quarter of a mile long and about 50 feet high. At the western end of the section the following beds are exposed:—

(4) Brown boulder-clay, with few stones.
(3) Brown sands, strongly current-bedded towards the east.
(2) Brown clay, with few stones.
(1) Fine white sands interbedded with fine gravel, often highly contorted.

Farther east, a thickness of 3 feet of brown sandy boulder-clay is exposed at the base of the section. This contains Tertiary basalt and many striated boulders of Carboniferous Limestone, also granites and hornblende-granites. At the road end this clay thickens out to 10 feet, but its base is not exposed.

Three-quarters of a mile farther east the cliffs are 15 feet high, and show at the base a grey clay which is very poorly exposed, and then the following series:—

(5) Coarse angular gravel.
(4) Yellow sands (8 feet).
(3) Contorted sands and clays (4 feet).
(2) Layer of pebbles of Carboniferous Limestone.
(1) Grey clay (1 foot +).

On the beach along this section of the coast lie thousands of large boulders. These include the whole suite of igneous rocks from the Carlingford–Slieve Gullion massif, and also many examples of Carboniferous Limestone and Silurian grit. Mourne Mountain granites do not occur.

IX. Summary and Conclusions.

In studying the glacial geology of a country three principal forms of evidence are available: (1) the roches moutonnées and striated surfaces; (2) the drift-deposits, including erratics; and (3) the various types of dry channels produced by the water draining away from the ice, or overflowing from temporary ice-dammed lakes.

The roches moutonnées and striated surfaces in the district now under consideration have been studied by the officers of the Geological Survey, and most of those which are exposed are marked upon their 1-inch maps. In some cases the exact bearing of the striations is given in tabular form in the explanatory memoirs accompanying the sheets. This work has been done with extreme care and accuracy, and in but few instances have I been able to add to the list of the recorded examples, and that only in cases where a new excavation has recently exposed them.

An early attempt was made by the officers of the Geological Survey, on the suggestion of the late Prof. E. Hull, to determine the general direction of ice-flow over the North of Ireland by means of these striated surfaces, and, as a result of their investigations, a paper was published by J. R. Kilroe on the Directions of Ice-Flow in the North of Ireland.[1]

In this paper it is pointed out that the striations recorded on the maps of the Geological Survey may be resolved into two sets running approximately at right angles to each other, and these are respectively attributed to (1) a glaciation by ice from Scotland, and (2) a later glaciation by ice from a great central snowfield (axis of glacial movement) running across the North of Ireland

[1] Q. J. G. S. vol. xliv (1888) pp. 827–33.

Fig. 10.—*Map showing the glaciation of the northern part of the British Isles.* (*J. R. Kilroe.*)

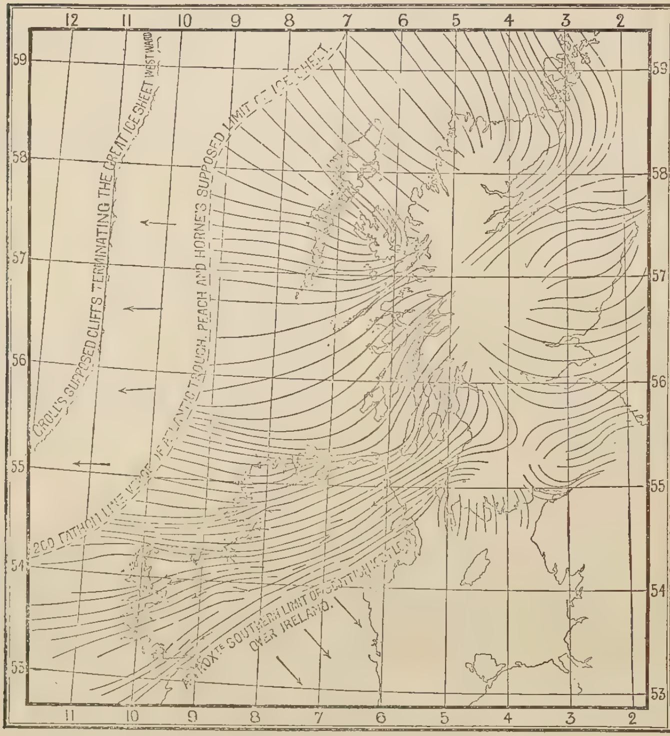
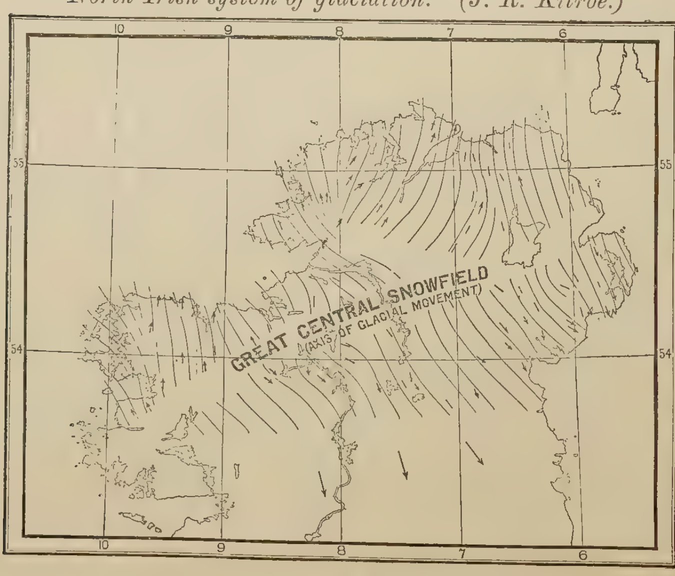


Fig. 11.—*Map of the North of Ireland, showing the North Irish system of glaciation.* (*J. R. Kilroe.*)



from east to west. Kilroe's paper is illustrated by two maps (*op. cit.* pp. 828 & 831) showing his interpretation of the ice-movement during the Scottish and Irish glaciations: these maps are reproduced in figs. 10 & 11, for purposes of comparison with my own interpretation.

Kilroe appears to have made the assumption that an ice-sheet flowing across the grain of a country would produce only striæ parallel to its general direction of movement, or, in other words, that the movement of the lower layers of the ice, entangled amid the irregularities of hills and valleys, would conform to those of the main mass above.

We need not be surprised that the conclusions arrived at in the paper under consideration should prove to require some modification, seeing that they are based upon the study of the striations alone, without due regard to the nature of the drift deposits or to the transport of erratics.

The drift-deposits and erratics have been studied by several observers, and many descriptions of local sections have been published. The most important of these are to be found in the Memoirs of the Geological Survey of Ireland, also in the reports issued from time to time by the Geological Section of the Belfast Naturalists' Field-Club, and published in the Transactions of that Society, to which I am indebted for many records of erratics.

The first references to the overflow-channels or 'dry gaps,' as being connected with glaciation, are to be found in the Drift Map of the Belfast District, published by the Geological Survey in 1904, and in the accompanying Memoir.

That there was something abnormal about some of the valleys in the North of Ireland appears to have been noticed by Joseph Nolan, of the Geological Survey, although he did not connect them with the action of ice. In the explanatory memoir to Sheet 34 (1878), on p. 8, Nolan writes:

'These tablelands [near Pomeroy] are intersected in every direction by deep winding valleys and ravines, which sometimes present very bold and striking characters. Since the formation of the older of these valleys and ravines the physical geography of the district appears to have undergone considerable alteration, so that it is not unusual to find a ridge of hill cut through by a deep ravine, the denuding agents having operated in a direction at right angles to that of the original valley. Bernisk Glen, some 4 miles south of Carrickmore, is a remarkable illustration of this.'

By studying and combining these three types of evidence it is possible to arrive at fairly definite conclusions as to the sequence of events, although in a district so complicated in structure and relief as that now under consideration, much in the nature of minor detail must remain doubtful.

From the careful study of a great mass of observed detail, only the leading features of which are described in the foregoing pages, there emerge certain main conclusions which will now be stated.

During the early stages of the glaciation the dominant agent in

the glaciation of the North-East of Ireland was the Firth-of-Clyde Glacier. This great *mer de glace* had its origin in the Highlands, but reached its maximum development only when the eastern exit from the Central Valley of Scotland, the Firth of Forth, was closed by the advance of the North Sea Glacier from Scandinavia. At this stage the ice from the Grampians, and from the Southern Uplands as well, must have escaped westwards, largely by way of the Firth-of-Clyde Glacier. When this glacier reached the Irish coast, which a glance at a map of the British Isles will show to lie full in its track, it was cloven, part passing westwards to the Atlantic and part southwards through the North Channel to the Irish Sea.

As the ice increased in thickness, it gradually overtopped and submerged the cliffs of the Antrim coast and the Silurian uplands of County Down. The track of this ice is marked by the occurrence of Scottish erratics, including several easily identifiable rocks from Arran, and, most important of all, the riebeckite-eurite of Ailsa Craig. It has been shown that the ice of this glacier covered the whole of the counties of Antrim and Down and extended at least as far south-westwards as the town of Monaghan, whence the Ailsa Craig rock has been recorded.

Prof. J. K. Charlesworth informs me that he has found pebbles of flint in the drift on the flanks of Slieve Beagh, an observation which confirms the westward movement of the ice in this region, since the Cretaceous rocks occur only north-east of that locality.

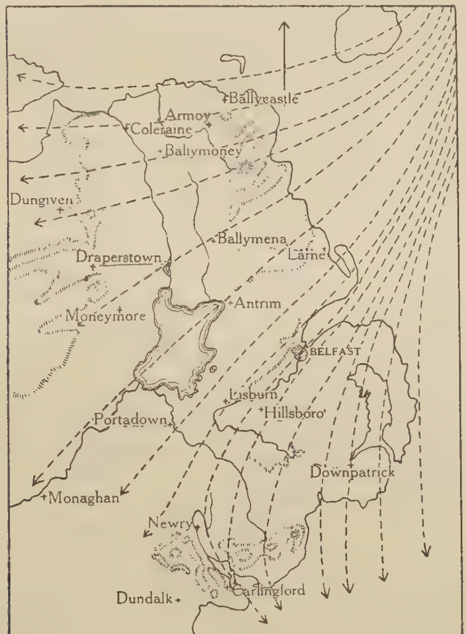
Though much of the country formerly covered by the Scottish ice was subsequently glaciated from the west, sufficient evidence remains in the distribution of *remanié* pebbles of Ailsa-Craig eurite and in the occasional occurrence of relics of an older boulder-clay (the contents of which indicate a movement of ice from the north-west) to support the conclusion that nearly the whole of the area described in this paper was invaded by the Scottish ice. The general trend of the ice-movement at this early stage is shown on the map (fig. 12, p. 419).

During this period there was doubtless much ice among the hills of Donegal, and an extension thereof accompanied by a shrinkage of the Scottish ice was responsible for the second phase of the glaciation of the north-eastern counties.

Two views are possible as regards the transition from Scottish to Irish glaciation: either the Scottish ice retreated, and left the ground vacant for the subsequent advance of the western glacier, or the two ice-sheets were in contact throughout the period of the Scottish retreat. I am of opinion that the latter of these hypotheses is the true one, and I base my view on the following facts. The track of the western ice throughout this district is marked by the presence of erratics from the Tyrone Axis; and the absence of these rocks from a large part of the area east of Lough Neagh and the line of the railway near Antrim Town and Cookstown Junction has already been discussed. The glacier which carried the Tyrone rocks to Randalstown and to Moira was sufficiently

powerful to reach Coleraine on the one hand and Newcastle (County Down) on the other, and yet it apparently failed to reach the eastern shore of Lough Neagh, or the low-lying land east of Cookstown Junction and round Ballymena. This, in my opinion, can only be explained on the supposition that those parts of the area were still occupied by lobes of the Firth-of-Clyde Glacier, which penetrated the country by way of the Ballyclare and Templepatrick Valleys, the valley of the Braid River above Broughshane, and Glenravel by way of Parkmore.

Fig. 12.—*General direction of the ice-movement during the earlier stages of the glaciation.*



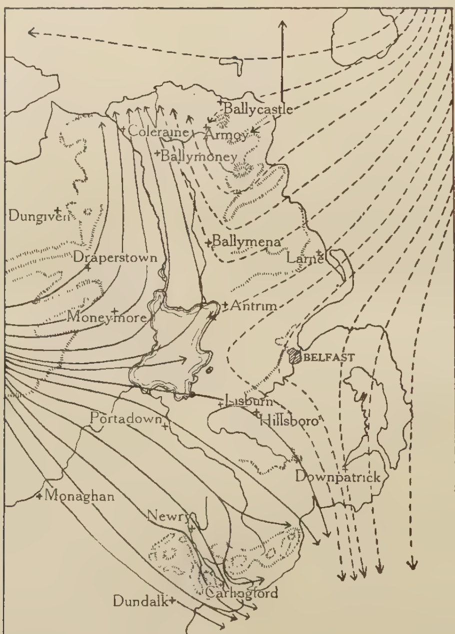
The western ice which crossed the Belfast Valley in the neighbourhood of Moira and Portadown, and ascended the Silurian uplands beyond, did not flow down the Belfast Valley beyond Soldierstown and Lisburn, and this again can only be explained on the supposition that the lower part of the valley was still filled by the Scottish ice, the deposits from which are there found in such profusion.

In this connexion the two boulder-clays and the cross-striæ on the uplands 3 miles south of Newtownbreda are of considerable interest. Although neither of the clays is known to contain the

Tyrone rocks, there is reason to believe that the upper one came from the west. It was probably formed, not by the direct action of the western ice, but because the head of the Scottish lobe which penetrated the Belfast Valley was deflected eastwards by the pressure of the Tyrone ice.

At its maximum extension the Irish ice probably reached the sea at the mouth of the Bann, and possibly from Bushmills to Ballycastle; but the traces of its maximum extension may have been obliterated by a subsequent re-advance of the Scottish ice, for which there is a considerable amount of evidence. This question will be dealt with later.

Fig. 13.—*General direction of the ice-movement at a later stage, when the Irish ice was at its maximum.*



In an easterly and south-easterly direction the Irish ice reached the sea at Newcastle (County Down), and at Dundalk, crossing the Silurian hills of County Monaghan at elevations up to 1200 feet. This stage of the glaciation is shown on the map (fig. 13).

After the maximum of the western ice-sheet, the Scottish ice would appear to have re-advanced, but whether in response to a diminishing thrust on the part of its Irish opponent, or to an

actual accession of power on its own part, there is insufficient evidence to show.

The great morainic system extending from Ballymoney to Glenshesk, with its correlated overflow-channels and lakes, the spreads of outwash-gravel in the valley of the Bann at Macfin, and the boulder-clay and gravels with Liassic materials at Drummaquill belong to this stage.

I tender my thanks to Mr. R. J. Welch, M.R.I.A., and to Mr. Robert Bell, F.M.S., who have frequently placed their intimate knowledge of the area at my disposal, and to many members of the Belfast Naturalists' Field-Club for the use which I have made of their records of erratics. I wish also to thank Prof. J. K. Charlesworth for information which he has from time to time given me with regard to the progress of his work on the glacial geology of the district to the west of that described in the present paper, and for his valuable suggestions and help when we traversed together the borderland of the two areas.

EXPLANATION OF PLATES XXIII & XXIV.

Plate XXIII.

View looking northwards down the Loughaveema Channel. (See p. 360.)

Plate XXIV.

Altiffirnan Glen, Carneighaneigh in the distance. (See p. 361.)

Discussion.

Mr. G. W. Lamplugh congratulated the Author upon the results of his wide investigation, which had thrown much new light upon the glaciation of North-Eastern Ireland. The limits of the western ice and its behaviour in regard to the invading ice-flow from the north-east were now made clear; and the detailed study of the physiographical features carved out by the ice-dammed drainage enabled us to visualize the conditions during all stages subsequent to the maximum glaciation.

He asked whether the researches of the Author had led him to any conclusion as to the unsatisfactory 'upper boulder-clay', which in this area, as in others, presented many problems in its composition and sporadic mode of occurrence. Had any deposits indicative of 'interglacial' conditions been discovered in the area examined?

The Author replied that he regarded the presence of boulder-clay above the current-bedded sands and gravels as evidence of periodic re-advances of the ice during the period of retreat, and there was no reason to suppose that the deposits, although similarly arranged, were contemporaneous in different parts of the area.

With regard to the question of interglacial periods, the Author knew of only one deposit in the district under consideration which

could possibly be interpreted as having been formed in such a period. This was a bed of silt near the mouth of the Dun River at Cushendun, at low-water level. The silt rested upon boulder-clay, so far as could be seen, and was covered by current-bedded gravels. These gravels are considered by the Geological Survey to be part of a raised beach, in which case the silt is (in all probability) post-Glacial. The silt yielded a few hazel-nuts, a root doubtfully referred to a species of willow, and a vertebra of a young pig.

[September 22nd, 1923.]

A. R. D. photo.

VIEW LOOKING NORTHWARDS DOWN THE LOUGHAVEEMA CHANNEL.

A. R. D. photo.

ALTIFFIRNAN GLEN, CARNEIGHANEIGH IN THE DISTANCE.

16. *The* Geology *of the* Schists *of the* Schichallion District (Perthshire). By Ernest Masson Anderson, M.A., B.Sc., F.R.S.E., F.G.S. (Read March 14th, 1923.)

[Plate XXV—Map & Section.]

Contents.

I. Introductory.

The district studied extends from the northern slopes of Carn Mairg across Strath Tummel, and includes a part of the valley of the Errochty Water. Except for some later intrusions, it is occupied entirely by crystalline schists. These belong in part to the series of Struan Flags—the probable equivalents of the Moine Gneisses of the more northern Highlands—and in a greater part to the so-called Dalradian Series, which here projects along a north-and-south axis for about 7 miles into the flags. The area includes the best development of the well-known Schichallion Boulder Bed, and has a historical interest from its association with Maskelyne's Schichallion experiment, which in itself led, at an early date, to a certain study of the geology.[1]

The district was mapped about the year 1900 by the late Mr. J. S. Grant Wilson, of the Geological Survey. Although a succession not previously recognized forms the basis of the map now presented, the latter follows Wilson's in many of its main features, and the investigation of the area would have been a task of far greater difficulty without the guidance of his previous work.

I am to a great extent indebted to Mr. E. B. Bailey for the inspiration which led me to take an interest in the problems of the Southern Highlands. Mr. Bailey, in a previous traverse of the ground here described, had anticipated that part of the conclusions of this paper which concerns the divisions of the Quartzite Group, and the relations of the rocks on its opposite sides. He has also made as yet unpublished observations on this Group in the neighbouring district of Blair Atholl, which he kindly gives me leave to

[1] John Playfair, 'Account of a Lithological Survey of Schehallien, made in order to Determine the Specific Gravity of the Rocks which Compose that Mountain' Phil. Trans. Roy. Soc. vol. ci (1811) p. 347.

quote. Certain other points which have a bearing on the geology of the area dealt with here are discussed in a paper which was recently presented by Mr. Bailey to this Society.[1]

In the Geological Survey Memoir[2] which accompanies the published map of this and the surrounding districts in Perthshire (1-inch Sheet 55, Scotland) the following (Dalradian) sequence is recognized :—

Quartzite and quartz-schist with pebbly conglomerate.
Schichallion Conglomerate ('Boulder Bed').
Limestone ('Blair Atholl').
Black Schist.
Phyllites, etc. ('Ben Lawers Schist').
Garnetiferous mica-schist.
Limestone ('Loch Tay').
Garnetiferous mica-schists ('Pitlochry Schists').
Green Beds.
Schistose grits ('Ben Ledi Grits and Schists').

The four members included in the bracket were supposed to be the only part that was present in the Schichallion district. Of this sequence the Quartzite was taken to be the upper limit, and the latest in point of time, with an unconformity at its base which caused it to rest upon either conglomerate, limestone, black schist, or phyllites.

I do not, in the present paper, propose to discuss the remainder of the sequence. It was taken to be in normal descending order, down to the Ben Ledi Grits. A more or less vertical belt of black schist, with an associated dark limestone, runs across much of the 1-inch sheet, and separates the main Quartzite outcrop which lies on the north-west from a Ben Lawers Schist area on the south-east. There can be no doubt that the sequence Quartzite—Black Schist—Ben Lawers Schist, which is seen along this belt, is continued south-eastwards, in the order given in the Memoir, to the Ben Ledi Grits. From the Ben Lawers Schist to the Grits it is a descending structural sequence,[3] of which the lowest members come to the surface on the south-east.

North-west of the belt of black schist just mentioned, matters are much more in dispute. This belt is highly graphitic in character, and shows a type of slaty cleavage which is absent from most of the rocks in the district. Black lustrous surfaces, developed along the cleavage, and usually at a slight angle to the sedimentary banding, are typical of this zone. The belt forms the summit of Ben Eagach, 9 miles east of Schichallion, and any black schist which is certainly on this horizon will be designated Ben Eagach Schist. Mr. G. Barrow, while accepting the Survey view that the Quartzite is later than the Ben Eagach

[1] 'The Structure of the South-West Highlands of Scotland' Q. J. G. S. vol. lxxviii (1922) p. 82.

[2] 'The Geology of the Country round Blair Atholl, Pitlochry, & Aberfeldy' 1905.

[3] This statement does not apply without qualification to other 1-inch sheets of the Geological Survey map.

Schist, has advanced the opinion that the limestone and the associated 'dark or leaden' schist of the Blair Atholl and Braemar districts are later than the Quartzite, and thus separate from the rocks of the Ben Eagach zone.[1] Mr. Barrow also holds that the Quartzite has upper and nether 'edges' of distinctly different characters.

II. Divisions of the Quartzite Group.

The Ben Eagach belt is laterally shifted by the Loch Tay Fault. West of this displacement the outcrop of black schist is more complicated; but the zone occurs without question on the south side of Carn Mairg. The quartzite which borders the belt is marked by a predominantly pebbly character. Non-pebbly bands occur as alternations, but are nowhere predominant. The pebbles, although sometimes larger, are perhaps most commonly of the size of peas. They consist of quartz and felspar, but those of quartz are most numerous. The higher parts of Carn Mairg show a typical development of this pebbly quartzite.

A small area of black schist, on the northern slope of the same hill, is surrounded by the pebbly quartzite, and from its highly graphitic character is certainly an infold of Ben Eagach Schist. This area is on the southern margin of the district which has been investigated, and will be used as a starting-point in the discussion.

A traverse beginning at this infold, and directed north-north-eastwards,[2] crosses first a zone of pebbly quartzite about a quarter of a mile wide. Following this is a broad belt of a somewhat distinctive grey mica-schist or granulite, with abundance of white mica. After nearly a mile of this pelitic type has been crossed with almost vertical dip, a quartzite is reached, which, from the almost entire absence of pebbles, it is impossible to suppose can be the same as that of Carn Mairg. This quartzite forms a strip running north-west and north, as shown in the map (Pl. XXV). Where crossed by the traverse it is flanked on the north-east by another belt of grey mica-schist, exactly similar to that already mentioned, and this again by a broad outcrop of non-pebbly quartzite, which includes in its course the higher parts of Schichallion.

Let us now follow these various outcrops along their strike. The Carn Mairg pebbly quartzite continues with steep dips in wedge-shaped fashion to the north, and, although it thins very much, it can be traced to beyond the River Tummel. Through the latter part of its course it is bordered on the west by a highly graphitic rock, along with a rock showing segregations of calcite, and containing acicular actinolite-crystals, which resembles certain parts of the 'calc-sericite' or Ben Lawers Schist. Much of this area is drift-covered, and the geology is further obscured by hornblende-schists which are probably original intrusive masses of

[1] 'On the Moine Gneisses of the East Central Highlands, & their Position in the Highland Sequence' Q. J. G. S. vol. lx (1904) p. 400.

[2] Not precisely along the line A B of the horizontal section (Pl. XXV).

basic igneous rock, irregularly introduced among the sediments. There is, however, one point near the summit of Creag an Fhithich (three-quarters of a mile south-south-east of Kinloch Rannoch) where the succession ? Ben Lawers Schist—graphite-schist—pebbly quartzite is clearly visible. The correlation of the graphitic rock with the Ben Eagach Schist is, therefore, almost certainly justified, and it should be noted that the occurrence in this area both of Ben Lawers Schist and of 'Black Schist' had been suspected by Mr. Grant Wilson.

The two belts of grey mica-schist and the two belts of non-pebbly quartzite are fairly persistent, as each is traceable for 5 or 6 miles in a curving course, with certain variations of thickness. The dips are nearly always steep, and sometimes vertical. As the Central Highland Quartzite has always been taken to include the rock which forms Schichallion, these facts seem to justify the conclusion that the former does not consist of one member, but is a composite group. A fivefold division might seem to be indicated, but against this view must be noted the great similarity of the rock composing the two belts of mica-schist. The two belts of non-pebbly quartzite are also indistinguishable in character, and this suggests that only three members are present, two of which are repeated by folding or some line of disruption. More convincing evidence of the division being only threefold had been obtained by Mr. Bailey in the Loch Tummel and Killiekrankie districts before I had mapped this part of the ground, and, relying on his so far unpublished work, I have divided the Quartzite Group into three, as shown in the table (p. 427). The non-pebbly and pebbly quartzites may be appropriately named the Schichallion Quartzite and the Carn Mairg Quartzite, while the mica-schist division has been named by Mr. Bailey the Killiekrankie Schist.

Turning next to the further side of the Quartzite, we may note that the non-pebbly band which forms the higher parts of Schichallion can be traced at least as far as the southern slopes of Beinn a' Chuallaich. For all this distance it has the grey mica-schist (Killiekrankie Schist) on the south and west, and the well-known Schichallion Boulder Bed on the east and north. The three formations are jointly affected by a change of dip which takes place west of Schichallion. In that mountain itself the Boulder Bed dips under the Quartzite, while farther north the Killiekrankie Schist and Quartzite dip more or less steeply under the Boulder Bed.

There is thus, I think, clear evidence, not only that the Quartzite in this district has separate 'edges': that is, both top and bottom, but also that the Boulder Bed is on the opposite side of the Quartzite from the Ben Eagach Schist and the remaining members of the Southern Perthshire succession. This conclusion, founded on what has been observed in the district under discussion, lends strong support to one part of the views put forward by Mr. Barrow with regard to the succession somewhat farther east.

III. The Beds between the Quartzite and the Struan Flags.

North and east of the bounding strip of Boulder Bed, it is easy to distinguish a series of rock-types, which I believe to form a stratigraphical sequence in continuation of that which has been already made out. These are the four lowest members of the following table, which is intended to represent the succession in an area extending from the Schichallion district to the south-eastern corner of Sheet 55 of the Survey map. That part of the series which is present near Schichallion is included in the larger bracket.

Ben Ledi Grits.	
Green Beds.	
Garnetiferous mica-schist (Pitlochry Schist).	
Loch Tay Limestone.	
Garnetiferous mica-schist (Ben Lui Schist).	
Ben Lawers Schist.	
Ben Eagach Schist.	
Carn Mairg Quartzite.	
Killiekrankie Schist.	Quartzite
Schichallion Quartzite, with	Group.
intercalated Boulder Bed.	
Main Boulder Bed.	
White Limestone.	
Banded Series.	
Grey Limestone.	
Grey Schist.	

The beds not included in the bracket, and the succeeding members as far as the Quartzite Group, are in inverted order, when compared with the previous table (p. 424). For reasons which will afterwards be given, I think it likely, though not convincingly proved, that the foregoing succession, when read upwards, is in true chronological order.

Grey Schist.—This is a pelitic or micaceous type, containing both white and brown mica. It is often so coarse as to be definable as a muscovite-biotite gneiss. The biotite is sometimes very largely altered to chlorite, while the non-flaky constituents include quartz, plagioclase (oligoclase to andesine), kyanite (sometimes well developed), and inconspicuous garnet. Two slides have been made of this rock in its coarser phase; both contain finely disseminated carbonaceous material, and one shows distinct flakes of graphite. The presence of this mineral would not be suspected in the hand-specimen; but, where the rock is finer, its graphitic nature is sometimes more pronounced. The Grey Schist must have been, though to a less degree than the Ben Eagach Schist, a carbonaceous sediment. Both these rocks were classed as 'Black Schist' in the Geological Survey map and memoir, but that name is more appropriate in the case of the Ben Eagach Schist. The two can easily be distinguished on field evidence, by the much more sparing occurrence of highly graphitic layers in the Grey Schist, at least so far as the district here described is concerned.

A very fine-grained pelitic rock is associated with the Grey Schist in one or two localities. It consists for the greater part of quartz, muscovite, and biotite, in minute grains and flakes, or of quartz and biotite with a certain amount of orthoclase. It is, however, partly calcareous, and one slide with calcitic laminæ shows fairly abundant scapolite. Carbonaceous material appears to be confined to the calcareous portions.

Grey Limestone and White Limestone.—These two, although separated by the Banded Series, are treated together for comparison. They are both coarsely crystalline non-dolomitic marbles. The former is the more massive, and, on the whole, the more purely calcareous type. A microslide of the Grey Limestone shows a matrix of large grains of calcite, enclosing some flakes of muscovite. There is an entire absence of any magnesian mica. The calcite contains a certain quantity of fine-grained carbonaceous material similar to that found in the Grey Schist. Two slides of the White Limestone both show magnesian mica, and one has finely-developed tremolite, which is well seen in the hand-specimen. In neither case is there carbonaceous material. These distinctions correspond more or less with the differences observed in the field. The Grey Limestone is typically dark when unweathered; and the weathered material, though lighter, has usually a perceptible greyish tint. The White Limestone is lighter when unweathered, and has a characteristic creamy weathering. The brownish magnesian mica seen in the slides is a very common constituent. Samples of Grey Limestone dissolved in hydrochloric acid leave a residue which is partly black, with the property of marking paper, while this type of material is absent from White Limestone residues. It is, therefore, fairly clear that the Grey Limestone owes its colour to the presence of carbon.

Banded Series.—This division was taken by Mr. Wilson to be a 'sheared' part of the Quartzite. It contains at least one rather massive band of quartzite, but consists for the greater part of very rapid alternations of siliceous and micaceous rock. The two types are sharply contrasted in colour, owing to the large amount of biotite in the micaceous layers. Often several bands of each type are crossed in the distance of a foot.

There is a tendency to rusty weathering in this series, and it is only with difficulty that fresh material can be obtained. A slide cut from a siliceous band shows a mosaic consisting of about 75 per cent. of quartz-grains, and 25 per cent. of felspar. The latter is altering into some flaky material, and the individual quartz-grains are surrounded by films of limonite. A slide cut from a micaceous band shows abundant flakes of dark biotite, set in a matrix like the rock just described. The felspar is however unaltered, and, though untwinned, is either oligoclase or andesine. Muscovite is entirely absent.

IV. Chronological Order of Succession.

General considerations.—The evidence for the relative order of these four divisions, and their relation to the Boulder Bed, lies wholly in their surface-distribution, as shown by the mapping. The Banded Series is an almost unmistakable type, and there are numerous sections in which one passes from it across Grey Limestone into Grey Schist; while, again, one constantly passes from Banded Series into Boulder Bed, with or without an intervening White Limestone. The White Limestone, it is true, is sometimes absent. This may be due to an unconformity, or to the fact that, being the thinnest member of the series, it is the most liable to be cut out by unrecognized lines of movement.

Alternative methods of reading the succession have been tried, but without success. For instance, the Banded Series contains what is here regarded as an intercalated quartzite. Could this quartzite, however, be that of Schichallion? The answer is that banded material is not observed along the margin of the Schichallion belt, and it is unlikely that, if this division had rapidly thinned out, its shore-line should everywhere be concealed by a comparatively narrow strip of Boulder Bed.

Errochty section.—A study of the district south of the River Tummel is enough in itself to decide the sequence, but ample confirmation can be found in the area farther north. East of Druimchastle bands of Killiekrankie Schist, Schichallion Quartzite, Boulder Bed, White Limestone, and Banded Series descend the hill-slopes in that order. A more complete section is seen in the Errochty Water, near Trinafour. West of the junction of the Dalradian System with the Struan Flags, some distance above the new, but below the old bridge, the Grey Schist is first met with. The old bridge rests upon a foundation of Grey Limestone, and above it the Banded Series is crossed. This ends with a narrow band of White Limestone, the other side of which is a small fault, bringing on the Boulder Bed. The limestone is, however, repeated a little farther up stream, and seen in unfaulted contact with a calcareous rock, which merges into the conglomerate. Higher up stream the latter gives way to Quartzite, and finally to a broad belt of Killiekrankie Schist.

The evidence for the lower part of the succession shown in the table (p. 427) has now been presented. The upper part extends through a large area of Perthshire, and has not been a subject of dispute. If the lower part is accepted, and proves capable of extension to other districts, it is suggested that the whole sequence should be known as the Perthshire Dalradian Succession. So far, I have not been dealing with the question whether the time-sequence of the table is up or down.

Boulder Bed.—There are, as shown in the table, possibly two

horizons of Boulder Bed, the main bed already mentioned in the text, and a thinner bed which is intercalated in the Schichallion Quartzite.

As recognized in the Geological Survey memoir, the main bed consists of two subdivisions. One of these has a micaceous, merging in places into a partly siliceous, matrix, while the other is highly calcareous. On the hill-slope east of Druimchastle the former division borders the Quartzite, and the latter the White Limestone. The same arrangement holds in the Errochty Water, except where the limestone is margined by a fault. There can be little doubt that this is the general relation, though one or both of the subdivisions may be missing, and the sequence is often confused by minor folds.

The non-calcareous part of the Boulder Bed is extraordinarily unbedded. The uniformity of the matrix and the haphazard arrangement of the boulders strongly suggest that it is a tillite,[1] or altered boulder-clay. The character of the boulders is discussed in the Memoir, and it need only be mentioned that they consist for the greater part of quartz and quartzite, and 'granite' or nordmarkite. The calcareous division has often markedly carious weathering, and has been named by Grant Wilson the 'honeycomb rock.' It contains abundant inclusions of a substance which may be the White Limestone. Their derivative nature might possibly be questioned, as they resemble the segregations of calcite which occur in some parts of the Ben Lawers Schist. There is, however, a small but definite admixture of quartzose fragments, which prove this division to be an integral part of the Boulder Bed.

It is worthy of note that what are apparently limestone fragments are not confined to the calcareous division of the Boulder Bed, but occur more sparingly in the non-calcareous part. Within my experience these are best seen in the strip of Boulder Bed which borders the Schichallion quartzite-belt, beside a small stream not shown in the 1-inch map, at a point 1500 yards north-east of the summit of Schichallion. This observation has an important bearing, as it is hardly possible to question that, in this case, we are dealing with fragments of a pre-existing calcareous rock. The material is creamy weathering, and non-dolomitic, and may well be derived from the White Limestone. This would imply that the Boulder Bed was the later formation. If this be not the chronological order, there is no member of the succession nearer than the Ben Lawers Schist that can be regarded as a source.

[1] A glacial origin is assigned to the Portaskaig Conglomerate by James Thomson, who, however, did not class it as boulder-clay ('On the Geology of the Island of Islay' Trans. Geol. Soc. Glasg. vol. v, 1877, p. 211). The point has been discussed by Mr. Bailey ('The Islay Anticline' Q. J. G. S. vol. lxxii, 1916–17, p. 142). The identity of this conglomerate with the Schichallion Boulder Bed has been regarded as probable since the time of Macculloch; but, as regards the latter bed, the suggestion that it is a tillite does not yet seem to have appeared in print.

The siliceous fragments in the Boulder Bed may be derived in part from intercalations in the Banded Series, although it is possible that many of them were originally vein-quartz. The 'granite'-boulders are the only type for which there is no possible local source. The latter have not been found in the calcareous division, and are nowhere more abundant than quite close to the Quartzite edge. If the order in time is Quartzite—Boulder Bed—Limestone, this implies that the only constituents of the conglomerate which are certainly far-travelled were among the very earliest to arrive *in situ*. If this order holds, it may also be noted that the Boulder-Bed, when deposited, must have had a calcareous top. The early arrival of the 'granite' seems to be an unlikely feature in a tillite. The calcareous top—if it be a top—is overlain by limestone, and if it be a boulder-clay top this can only be regarded as a curious coincidence. Except, however, where, as noted below, it comes against the Quartzite, the Limestone is always flanked by the 'honeycomb' rock, and the two appear to have a fundamental connexion. In fact the glacial hypothesis almost certainly implies that the order was Limestone—Boulder Bed—Quartzite, and, even apart from an ice-age, the facts are most readily explained if this was the case.

If this conclusion be correct, the order of superposition is that given in the amended table (p. 427), and the Grey Schist is the oldest Dalradian rock in the district.

This conclusion is in agreement with the facts recorded by Mr. Bailey in Islay.[1] The Portaskaig Conglomerate has, as is well known, a remarkable resemblance to the Schichallion Boulder Bed, and Mr. Bailey has found reason to believe that the former is succeeded in point of time by the Islay Quartzite, which may well be the equivalent of the Perthshire Quartzite Group.

The conglomerate which is supposed to be intercalated in the Schichallion Quartzite has a matrix that is more siliceous than any exposure which certainly belongs to the Main Boulder Bed. It forms two narrow strips on the northern slope of Schichallion, which are flanked on both sides by quartzite. One of these is only about 100 yards from the upper margin of the bounding band of Main Boulder Bed, which has already been mentioned. The narrow strip is here typically siliceous, while the main bed has a micaceous matrix, right up to the edge of the quartzite. Unless, therefore, one regards the former as an intercalation, one must suppose the margin of the main bed to undergo very rapid lateral variation. Although the point is far from certain, I regard the former as on the whole the more probable hypothesis, and have followed the Survey map in separating the two conglomerates. The siliceous type contains large boulders of 'granite,' and pieces of a finer-grained acid igneous rock, which is

[1] 'The Islay Anticline' Q. J. G. S. vol. lxxii (1916–17) pp. 132–59; see, in particular, p. 143.

also present in the Main Boulder Bed. These constituents may have been derived from the main bed by fluviatile or marine erosion. This theory assumes that the Quartzite is the later deposit, and that there is a certain amount of overlap at its base. It is unnecessary to suppose a readvance of the hypothetical ice-sheet.

Relations of the Boulder Bed.—It is probable, in any case, that the base of the Quartzite overlaps the Main Boulder Bed. A ground-moraine deposited on an irregular land-surface might well be absent in places, and this may explain the fact that the Quartzite is sometimes in very close proximity to the White Limestone. This is seen, for instance, in a tributary of the Errochty, about a mile west of the old bridge which crosses the parent stream. (It may, however, be due in part to lack of exposures that the Main Boulder Bed cannot be more continuously traced.) The White Limestone, as before remarked, is, for one reason or another, very inconstant. The Banded Series is relatively persistent, but at the northern end of the projecting area of Dalradian rocks most of this series appears to be absent, as well as the two members above it, in such wise that the Quartzite approaches the underlying Grey Limestone. How far these facts are due to erosion, and how far to subsequent movement, is difficult to determine. It seems, however, reasonable to assume that there was a period of elevation either before or after the formation of the Boulder Bed, which accounts for its irregularity. Even if the conglomerate was formed on a flat surface, its partly calcareous matrix and the limestone-fragments may be explained by glacial erosion. But, perhaps more probably, the surface over which the ice advanced was already an uneven one.

The hornblende-schists.—In this account of the stratigraphy of the district little mention has been made of the hornblende-schists. These are exceedingly numerous, and for the greater part they have not been shown in the accompanying map (Pl. XXV). They occur from top to bottom of the sequence, and do not appear to be constant at any particular horizon. They are, therefore, probably not original lava-flows, but altered dykes, or more likely, from their relation to the bedding, at least in large part altered sills. Isolated fragments of a similar amphibolite are seen in the Boulder Bed of the Errochty Water section. These must be the result of the regional metamorphism acting on pebbles of a rock like that which was concurrently transformed into hornblende-schist. It seems possible, therefore, that there were two periods of intrusion: one which preceded, and one which followed the formation of the Boulder Bed.

V. Structure of the Schichallion Area.

The northern syncline.—At their northern limit the Dalradian rocks are enclosed in a little syncline, which pitches out northwards, and are underlain, both in that direction, and on the east and west, with only a gentle discordance, by the Struan Flags. Within the syncline is an ascending sequence, from the Grey Schist to the Schichallion Quartzite.

Followed southwards the syncline broadens, and an area of Killiekrankie Schist appears in its centre. At the same time, the eastern limb becomes reversed. Somewhat south of the Errochty a structure occurs, which may be described by saying that the axial plane of the syncline is shifted a mile and a half to the west. The strike of the eastern limb is altered from north and south to east and west, resuming its original direction about 2 miles north-east of the summit of Beinn a' Chuallaich. The reversed dip of this limb is meanwhile maintained at rather a low angle.

The western limb becomes unrecognizable a little beyond the point where it crosses the Errochty, and the further use of the term 'syncline' refers only to the fact that Dalradian strata are bordered on both sides, and probably underlain, by flags. Southwards the syncline, as so defined, becomes split by a subsidiary anticline. The first sign of this is the appearance of a mass of Schichallion Quartzite, which forms the summit of Ben a' Chuallaich, and is bordered on both sides by Killiekrankie Schist. A strip of Boulder Bed then appears within the Quartzite, which at one point is seen in contact at both sides with, and overlying, a vertical upfold of 'honeycomb rock.' A little farther south, both the White Limestone and the Banded Series become visible. Although there is no sign of ordinary faulting, the eastern margin of the anticline is here a line of movement, as the White Limestone is brought sharply against Killiekrankie Schist, and nearer the Tummel the Banded Series is in contact with Schichallion Quartzite.

South of the Tummel the 'crest' of the anticline is formed by Grey Limestone and Grey Schist. On approaching Schichallion the strike bends round through south-east to east, while the dip of both limbs of the anticline, and of the eastern limb of the main syncline changes from steeply east to an angle of about 55° southwards.

The structural succession.—In the foregoing paragraphs it has been assumed that the structural succession seen at the northern end of the Dalradian projection is the general order of superposition in the district, despite minor folds, or even overfolds. This assumption is in agreement with the relations of Quartzite and 'honeycomb rock' south of Ben a' Chuallaich. It is strengthened by the behaviour of the two main groups in the area north-east of Schichallion. Here a quartzite, which probably belongs to the Struan Flag Series, and, if not, certainly overlies

these, dips under a Grey Schist and Limestone belt which is a continuation of that which borders the Dalradian projection farther north. The ascending order is :—Struan Flags : Quartzite : Grey Schist and Limestone : Banded Series : Boulder Bed : Banded Series : Grey Schist and Limestone : Banded Series: Boulder Bed: Schichallion Quartzite-belt (see horizontal section, Pl. XXV). The second belt of Grey Schist and Limestone marks, as I take it, the crest of the subsidiary anticline. The Flags must also dip under the Dalradian Series near the foot of Loch Rannoch, although the line between them is here difficult to define. Quite apart from any evidence outside this district,[1] this seems the most likely general order, though it must be emphasized that in this particular connexion we are considering only the structural sequence, as regarded on a large scale. If my conclusion holds, then the Dalradian Series as a whole overlies the Struan Flags along this part of their border.

Where the Grey Schist is marginal to the Flags, as it is for many miles, it must be concluded that it is structurally the lowest Dalradian member. As there is some ground for thinking that it is also the oldest, it may follow that the Dalradian System, although intensely folded, has not here been subject to any very broad or general inversion.

This statement is not meant to be applied without reservation to the area south-west of Schichallion, and it may or may not apply to most of the western border of the 'projection', where the Grey Schist, as will be noted later, no longer forms the margin. It certainly does not hold near Loch Tay, where the Loch Tay Limestone dips under the Ben Lui Schist and Ben Lawers Schist, and where, if my premises are correct, there must be inversion.

The Allt Mor Limestone.—The structure of the ground immediately south-west of Schichallion has already been briefly described; but one point remains to be noted. On the Tempar Burn, about 2 miles south-east of Kinloch Rannoch, a little island of limestone, accompanied by graphitic schist, appears within the borders of the Schichallion Quartzite-belt. A similar limestone (with a remnant of graphitic schist) forms a fairly broad strip in the valley of the Allt Mor, where it intervenes between the south-eastern belt of Schichallion Quartzite and the north-eastern belt of Killiekrankie Schist. The three formations border each other rather abruptly; but the Killiekrankie Schist is transgressed by the limestone, when it is followed eastwards, and the latter curves round the end of the eastern spur of Schichallion almost in contact with the mountain-forming Quartzite. A tongue of limestone shoots westwards along the northern slope, with Quartzite above and below; but the main mass continues east-north-eastwards,

[1] See E. B. Bailey & M. McGregor, 'The Glenorchy Anticline (Argyllshire)' Q. J. G. S. vol. lxviii (1912) pp. 164–78. The 'Eilde Flags' of that paper are probably the Struan Flag Series, and the 'unclassified schists' are part of the Perthshire Dalradian.

accompanied by a rock resembling the Grey Schist. This limestone is too massive to be regarded as a local intercalation in the Quartzite Group. If, on the other hand, it be taken as Grey Limestone, as I believe it to be, its method of occurrence needs some explanation. It is true that, in the extreme north of the district, the Grey Limestone comes near the lower margin of the Schichallion Quartzite. But, in the nearer ground, immediately north of Schichallion, the intervening members are strongly developed. A line of movement has been suggested, in order to account for the duplication of the outcrops of Schichallion Quartzite and Killie-krankie Schist, and it is possible that one margin of the limestone is a continuation of this line. Neither margin can, however, be an ordinary fault-line, as both are much twisted, or folded, and there is no visible sign of crush. It is possible that the explanation lies in a folded rupture, which may either have been a normal fault, or a thrust. Conceivably, two such faults are needed to explain the relations. The general deformation and metamorphism of the period of the folding may have destroyed the more tangible evidences of movement.

VI. Line of Contact between the Dalradian Series and the Struan Flags.

A junction occurs on the banks of the Tummel, a short distance east of Dunalastair, and 3 miles east of Kinloch Rannoch. As in the ground north-east of Schichallion, the Grey Schist is the marginal member of the Dalradian Series. The strata are here nearly vertical, and, as the Flags are approached, little bands or lenticles of rock of a siliceous type appear in the Grey Schist. The margins of these bands are perfectly sharp, and there is no gradation of type. Following the northern bank one reaches a little trough-shaped hollow, which does not appear on the other less accessible side of the river, and which there is no reason to suppose is a fault-line. On crossing this, one passes from thoroughly pelitic Grey Schist into an unbroken and typical section of siliceous flags.

The marginal belt of Grey Schist continues to beyond the Errochty Water. The change from micaceous schist to siliceous or semipelitic rocks of the flag group is always abrupt, and can sometimes be fixed within a few yards. Infolds or intercalations of flagstone type are, however, sometimes found within the Grey Schist, as in the Tummel section.

At the northern end of the Dalradian outcrop, the border of Grey Schist is present striking east and west, but considerably thinned: it cannot be followed beyond this point. The Grey Limestone, on the other hand, passes round the end of the syncline, and may be traced for half a mile along its western side. Where last visible the marble must be in close proximity to rocks of the flagstone group, although the latter are not seen absolutely in place.

Some time has been spent in attempting to trace the further

course of the flagstone margin, but no line has been drawn that can be regarded with confidence. The reason is that, although the Struan Flag Group of this district contains no rock of a thoroughly pelitic nature which matches the Grey Schist, it does contain horizons which resemble the less thoroughly micaceous Killiekrankie Schist, and probably also quartzites of Schichallion type. It is, however, certain that neither the Grey Schist, Grey Limestone, Banded Series, White Limestone, nor Boulder Bed can be seen south of the Errochty Water on the western margin of the syncline. On the other hand, one passes from areas of Killiekrankie Schist, through rocks of the same type which may belong to either series, into unquestionable flags. In a stream which rises about a mile west of Ben a' Chuallaich, and joins the Tummel at Kinloch Rannoch, rocks resembling the flagstone series are seen in contact at one point with what may be the pebbly quartzite, and at another with what is almost certainly Ben Eagach Schist.

We are, in any case, justified in regarding the junction of the two series as, in part at least, a strong line of discordance. If it is an unconformity, the amount of erosion, or the amount of overlap, must extend from Grey Schist certainly to Killiekrankie Schist, and probably to Ben Eagach Schist.

The following considerations appear to tell against the explanation of the facts by means of an unconformity. For the sake of argument, let it be supposed that the unconformity exists. Then there are two alternatives: either the Dalradian Series has been deposited over the flagstones, or the flagstone series over the Dalradian. If the Dalradian Series be the later, the discordance already noted must be due to the overlap one over the other of different members of this group.[1] The Grey Schist, being for so long a distance marginal to the flagstones, must be taken as the oldest of the formations which have succeeded them, and it was followed by the Grey Limestone. In this case it is difficult to explain the observed adherence to type of these two Dalradian members, where they abut against their shoreline. The former is an altered carbonaceous mudstone, and the latter a clear-water deposit. Some degree of lateral variation at least was to be expected, and we have also to account for the absence of conglomerate.

It may be supposed, however, that, while an unconformity exists, the order in time is the reverse of that already considered, and the Struan Flag Series originally overlay the Dalradian. It then

[1] This relation has been figured by Prof. J. W. Gregory ('Handbuch der Regionalen Geologie' vol. iii, pt. 1, 1917, p. 38). Prof. Gregory, however, shows the Blair Atholl Limestone and Graphitic Schists as resting upon the Quartzite. As the former presumably correspond to the Grey Limestone and Grey Schist of this paper, it is difficult to explain the consistent intervention of a belt of Grey Schist, Grey Limestone, etc., between the flags and the Quartzite, along the eastern margin of the 'syncline', on the basis of Prof. Gregory's diagram.

follows that, from its marginal character, the Grey Schist is the latest of the underlying formations, and the truncation of the different horizons of the Dalradian Series is due to erosion. The following facts may then be noted. The flags in this district contain arkoses and gritty quartzose rocks which are occasionally almost to be described as pebbly, but nothing in the nature of a conglomerate. Also, the same type of truncation along the junction as that which has been observed in the Dalradian Series, takes place to a certain extent among the flags. In following the line of contact where it is sharply defined, the marginal member of the Struan Flag Group is first a gritty arkose, which is seen beside the Grey Limestone, at its southernmost exposure on the west side of the 'syncline'. It varies to a semipelitic type, which borders the Grey Schist in the Errochty-Water section. Farther along the boundary the marginal rock consists of typical flags and a flaggy quartzite, as, for instance near Dunalastair; and lastly, as before mentioned, one encounters a massive quartzite.

It is, therefore, necessary to suppose that, even on the present hypotheses, there is a certain amount of overlap. It may be argued that, on an uneven floor, one should find in the flagstone series recognizable fragments of the underlying eroded rocks, such as Grey Schist and Grey Limestone. Such fragments are not found, and, as has been previously shown, the late position in the Dalradian sequence, which is assigned to the Grey Schist on the two hypotheses here set forth, is in itself unlikely.

If the discordance be due to a plane of movement, there are two ways in which the facts may be regarded. Either the junction with the Grey Schist is a natural one, which terminates against this plane near the northern end of the syncline, or the whole line of contact consists of a folded fault or faults.

A fact with a possible bearing on the existence of a marginal dislocation has been noted in the Geological Survey Memoir by J. S. Grant Wilson, who writes as follows:—

'This normal north-east strike is modified in the area between Glen Garry and the Erichdie [Errochty] Water by the lines or narrow belts along which the beds are violently contorted and thrown into a series of sharp vertical folds; the strike being at right angles to that of the rocks on either side. The most prominent of these lines appears to form the north-east boundary of the Trinafour complex, ... and runs in a W.N.W. direction from Meall Dall-chealach, crossing the Garry at the foot of the Allt Stalcair. It gives rise to a conspicuous feature, forming a ridge which projects above the surrounding moor.' (*Op. cit.* 1905, pp. 70–71.)

The facts recorded both on the published map and on Mr. Wilson's field-map seem, however, to indicate that the line of movement is continued along the western, more probably than along the eastern margin of the Trinafour complex, which means what is here called the 'syncline'. If this be the case, it must bend round so as to become parallel to the strike, and at the same time cease to form any prominent feature. It will have been noticed

that it is along the western margin that it is necessary to suppose the more violent part, or possibly the whole of the discordance.

The margin of the Struan Flags has now been followed by the Geological Survey staff to near Loch Awe. For most of this distance the flags do not come directly into contact with rocks which belong to the sequence that in this paper has been described as Dalradian. There is an intervening zone, the relations of which have been discussed by Mr. E. B. Bailey & Mr. M. McGregor.[1] When, however, the rocks of the sequence are reached, they belong to the Quartzite Group, or to the Ben Eagach Schist, or to that part of the succession here regarded as later. The Boulder Bed, for certain, does not reappear. It is thus seen that, whatever be the cause of the transgression along the 'syncline', whether folded fault-line or unconformity, it is a far-reaching, and not a local phenomenon.

While I favour the hypothesis of a folded line of movement, I do not think that this discontinuity need necessarily have been a thrust-line. A normal fault of large dimensions, which had been subject to intense shear, might explain the phenomena. Such a shear might bring all original structures, including the fault and the bedding, into approximate parallelism. This theory probably implies the necessity of a general overriding movement, along the Dalradian border, which came from either the east or from the south.

Such a movement might not itself be localized in a thrust-plane, but might act on a pre-existing normal fault so as to produce somewhat similar results.

VII. Regional Metamorphism.

The degree of metamorphism has been such as to convert the limestones of the district into rather coarsely crystalline marbles. The argillaceous rocks are partly pelitic gneisses, although in other cases they may be described as schists. It may be noted that garnet is abundant in parts of the Killiekrankie Schist, and also occurs, though more sparingly, in the Grey Schist. Kyanite is frequent, and sometimes forms fairly large crystals, in all the chief pelitic rocks of the district. These include the Killiekrankie Schist, the Grey Schist, and parts of the matrix of the Boulder Bed. The Grey Schist also contains well formed staurolite in one locality.

The amount of shear has been great enough to bring the sedimentary banding of the different types into general parallelism with the plane-foliation.

The structure known as 'linear foliation' is a common feature in the district, though not more so than in various other parts of the Highlands which I have mapped. This phenomenon does not

[1] Q. J. G. S. vol. lxviii (1912) pp. 172 *et seqq.*

appear in the comparatively unaltered rocks of the Lochawe Syncline, but seems to be a very widespread characteristic of those parts of Northern Scotland where the metamorphism has reached a somewhat higher stage. I have previously described it as follows (in 'The Geology of Mid-Strathspey and Strathdearn' Mem. Geol. Surv. 1915, p. 22):—

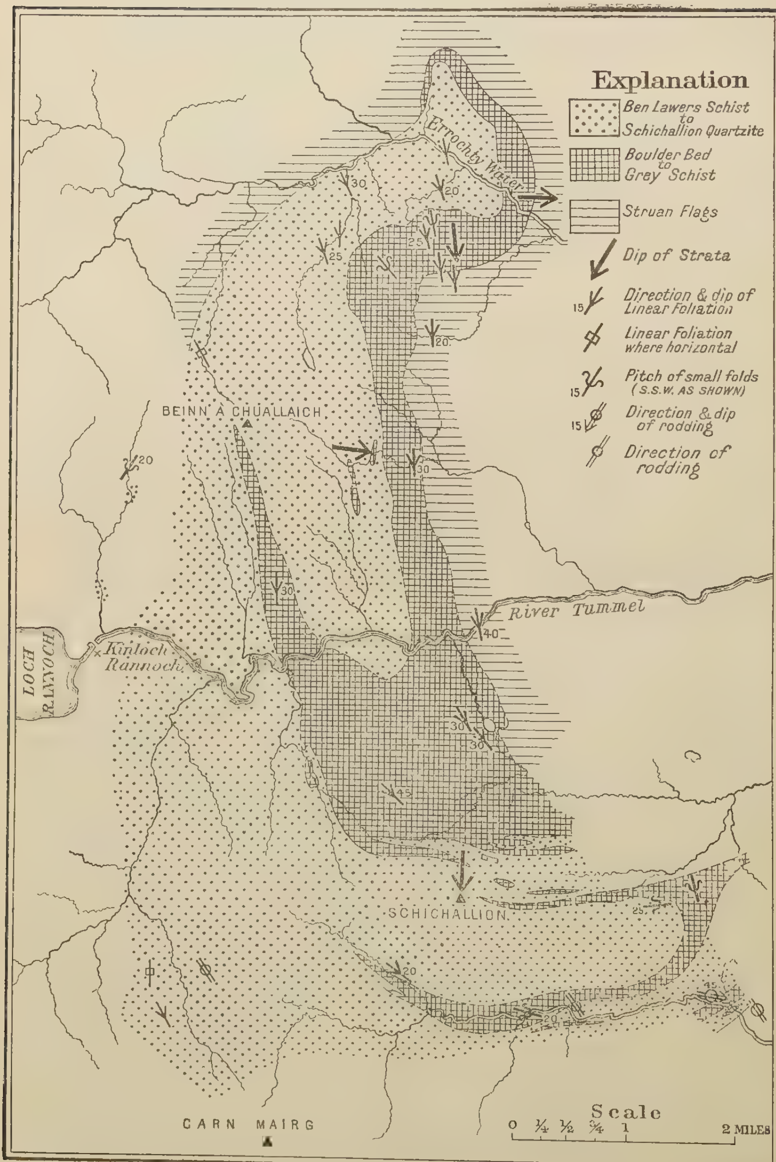
'. . . . a sort of striation visible on practically any well-exposed divisional or bedding-plane of the granulites. This is not rodding in the sense of any actual elongation of the minerals, though the mica-flakes are all arranged so as to have one direction parallel to that of the striation. It seems rather to be due to a minute corrugation of the micaceous laminæ, the folds of which have their axes parallel to the striations. It is none the less probably caused by stretching, and the striations probably coincide with the direction of shear. The impression produced on an observer is that the shearing must have been intense.'

I also noted that this lineation could be seen to be parallel over wide districts, even where the bedding changes strike. This is well illustrated in the Schichallion district. Throughout the whole of the 'syncline,' and the neighbouring parts of the flagstone series, the linear foliation dips at gentle angles (see map, p. 440) southwards: it is thus usually parallel to the strike. Where, however, the latter alters to east and west, south of the Errochty Water, the direction of the former is unchanged. It may be further noted that the direction and dip of the lineation is almost invariably that of the pitch of the smaller folds. Thus, certain folds which affect the Grey Limestone, in the area of east-and-west strike just mentioned, and are shown on the map, pitch at low angles southwards.

In one respect the description quoted above requires to be modified as regards the Schichallion district. In the micaceous rocks the phenomena are the same; but in the hornblende-schists there is actual rodding or elongation of the crystals, which always follows the general direction. Tourmaline-crystals, where formed, have also a sub-parallel arrangement: this is shown by a slide of the matrix of the Boulder Bed. Kyanite-crystals, on the other hand, are arranged in the plane of general foliation; but their directions of maximum elongation lie haphazard in this plane. This is well seen in a tributary of the Errochty Water, which joins it from the south about half a mile above the Allt Choin. The same stream-section shows rodded hornblende-schists.

South of the Tummel the lineation curves round gradually, in conformity with the change of strike, and dips in general eastwards or south-eastwards. I believe this appearance to have been produced somewhat after the manner of a flow-structure; but, whatever be its cause, it seems to be a phenomenon worthy of further study, and one that may throw some light on the origin of the Scottish schists.

Linear foliation and minor folding in the Schichallion district.



cf. Elles. QJ 192

VIII. Summary and Conclusions.

So many debatable points have been dealt with in this account of the district that it may be well, in summarizing the results, to separate those for which the evidence seems clear from those which are to some extent conjectural.

(1) Among the former results are those which have to do with the Dalradian succession. The facts outlined in this paper, and shown in a general way on the map, suggest the following conclusions:—

(*a*) The quartzite, previously taken to be a single unit, is in reality a composite group. It contains a central mica-schist and marginal components which are quartzites of different characters.

(*b*) On the one side of the quartzite group is a graphite-schist, and a succession following this in the order previously determined by the Geological Survey.

(*c*) On the other side is the Boulder Bed, and a succession following it as given in the table (p. 427).

It is very difficult indeed to escape these deductions.

(2) The study of the Boulder Bed has led to a further conclusion: namely, that the Grey Schist is probably the oldest member, and the Ben Ledi Grits the youngest member of the succession as stated. The validity of the evidence depends, to some extent, on the assumption that the Boulder Bed is a tillite, and while, with others, I favour this assumption, I do not claim that an inference derived from it can as yet be regarded as proof.

(3) A certain amount of local discordance is associated with the Schichallion Boulder Bed. The facts may be explained by supposing that the conglomerate was formed on, and more or less at the expense of, an already partly eroded surface of White Limestone and Banded Series, and was afterwards overlapped by the Schichallion Quartzite.

(4) The structure of the district is more obscure than the stratigraphy. It is obvious that the folding has been extremely complex. Such complexity might have been produced from a rock originally in horizontal layers, if it had been acted on by a movement analogous to flow. It is necessary to suppose that this flow-movement itself was complex, although it may have been roughly parallel in direction over areas which extended for several miles. The field appearance known as linear foliation may be the visible indication of such a flow.

It is almost certain that in the Schichallion district, as in the country nearer Loch Awe, the general relation of the Dalradian Series to the Struan Flags is one of superposition. In a part at least of the district here described the supposed later members of the Dalradian succession overlie in the same general manner the supposed earlier members, and, speaking broadly, the sequence is probably uninverted.

The line of junction between the Dalradian Series and the flags

is discordant, both as regards the zones of the Dalradian and those within the flags. This discordance appears from the evidence to be more probably due to a folded rupture than to an unconformity, although I do not claim that the facts which support this conclusion form an absolute proof.

The study of this district has strengthened my belief that large horizontal movements have affected the Southern Highlands. These may, or may not, be connected with the appearances of flow-structure. At the same time, I think it as yet impossible to define their direction, or to say whether the discordances which they appear to produce need in every case have been due to thrusting, rather than to the distortion of large normal faults. In these respects I regard the subject as being at present in the speculative stage.

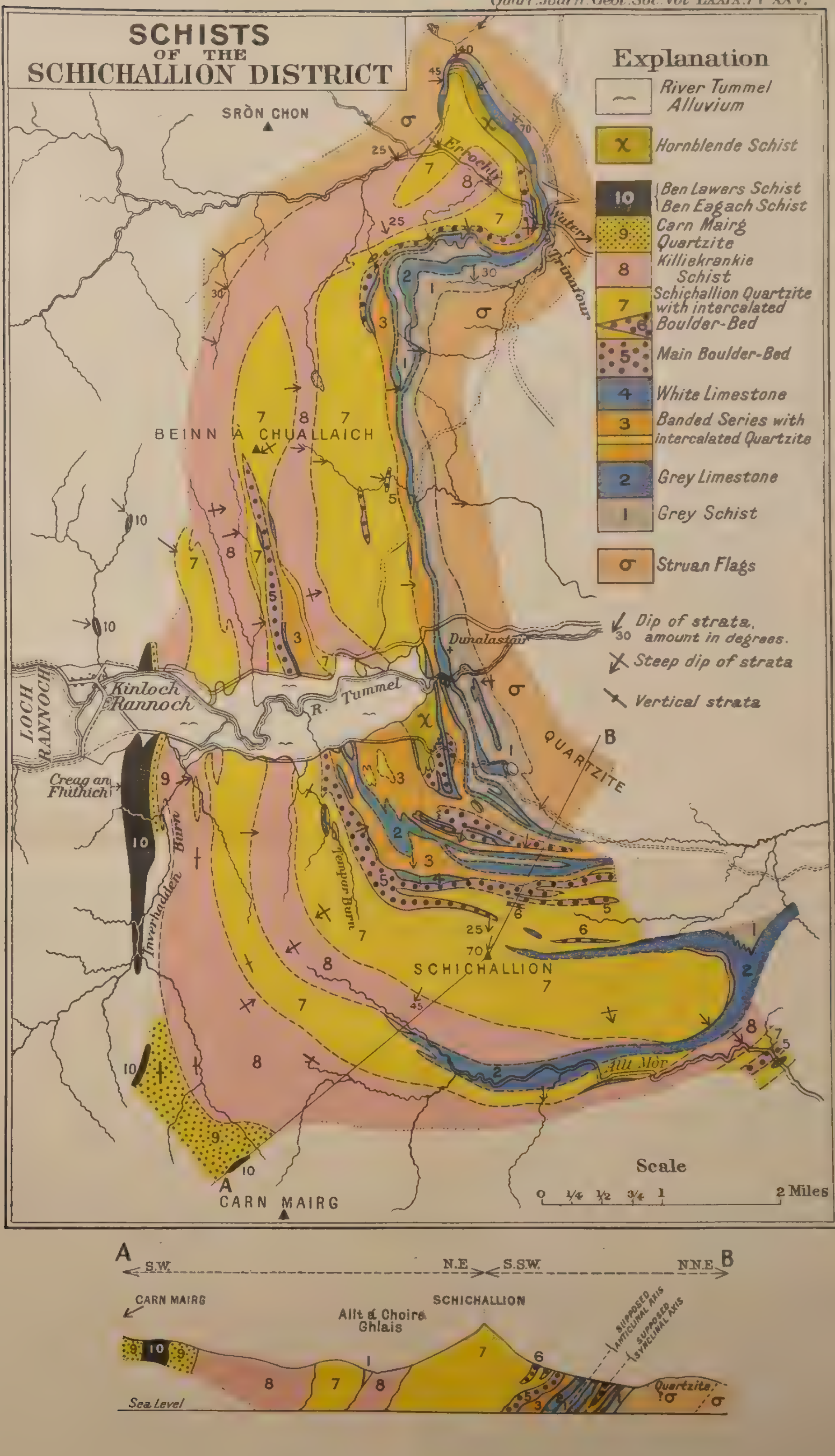
EXPLANATION OF PLATE XXV.

Geological map of the Schichallion district on the scale of 1 inch to the mile, or 1 : 63,360; and section across the same.

Discussion.

Dr. J. S. Flett said that this paper appeared to be an elaborately careful piece of work. It was of interest, as the Author's version of the sequence was in some respects different from that of Grant Wilson, and more complete. Two points especially attracted attention. One was the presumably upward sequence from the margin of the Moine rocks: this was in accordance with the views of other geologists who had recently been working on that group. The second point touched the relations between the Moine Series and the rocks south thereof. On this question the Author had, unfortunately, formulated no definite conclusion. An examination of the Author's map suggested that this line might mark a plane of movement; but, before it was assumed that the absence of certain groups was due to that cause, it was desirable to bring forward some evidence that these rocks had originally been deposited there, and had not subsequently been removed by erosion. Several features of the map, especially the Boulder Bed and its local distribution, suggested that contemporaneous erosion or non-sequences might be expected in that group.

Mr. G. Barrow drew attention to the difficulty of dealing with the details of recent papers on the Highland rocks, as new names were introduced for every new locality visited. With regard to the succession in the beds described in more detail in the Author's paper, certain facts were now well established. The pebbly portion of the Quartzite is the base of the bed, for it has been proved to overlie directly the true Graphite-Schist over a great stretch of ground. Beginning in South-West Aberdeenshire and coming south-west to Pitlochry, the speaker had noted that the base of the Quartzite is often blackened by minute specks


SCHISTS OF THE SCHICHALLION DISTRICT
Explanation
River Tummel Alluvium
Hornblende Schist
Ben Lawers Schist
Ben Eagach Schist
Carn Mairg Quartzite
Killiekrankie Schist
Schichallion Quartzite with intercalated Boulder-Bed
Main Boulder-Bed
White Limestone
Banded Series with intercalated Quartzite
Grey Limestone
Grey Schist
Struan Flags
Dip of strata, amount in degrees.
Steep dip of strata
Vertical strata
SRÒN CHON
Errochty
Water
Trinafour
BEINN À CHUALLAICH
Dunalastair
LOCH RANNOCH
Kinloch Rannoch
R. Tummel
QUARTZITE
Creag an Fhithich
Inverhadden Burn
Tempur Burn
SCHICHALLION
Allt Mòr
CARN MAIRG
Scale
0 1/4 1/2 3/4 1 2 Miles
S.W.
N.E.
S.S.W.
N.N.E.
Allt a' Choire Ghlais
Supposed anticlinal axis
Supposed synclinal axis
Quartzite
Sea Level

of material originally picked up from the still soft black mud below: this continues to the west of Pitlochry. Farther south-west the erosion went deeper, and small fragments of coherent mud were picked up and are now seen enclosed in the Quartzite. Still farther south-west these fragments are at times as large as the palm of a man's hand. That the Quartzite is above the true Graphite-Schist is thus clear.

Starting from the base and crossing the Quartzite, we reach the top, which is fine-grained and white. It is one of the most easily recognized horizons in the Highland rocks. It is perfectly seen in the coast-section at Portsoy, and the speaker had followed it for over 100 miles in the interior of the Central Highlands.

The area selected by the Author was not a good one for dealing with the succession, as the presence of the Boulder Bed at once showed that there was a non-sequence: that is, part of the series is always absent when this bed is present.

The speaker then referred to the succession described by him in the area of Glen Clunie.[1] He had shown that, going southwards, one notes a comparatively sudden hiatus. The Limestone is seen to rest upon a remnant of the Parallel Banded Series, and is occasionally quite close to the white edge of the Quartzite. The erosion is the same, whether the Boulder Bed be present or absent. A photograph of the base of the Limestone lying in an eroded hollow in the Moine Gneiss is published in the paper already cited.[2]

The approach to and recession from the edge of the Quartzite by the Blair Athol Limestone occurs repeatedly over a large area, and the published evidence shows that the Blair Athol Limestone is above the dark Schist and Little Limestone, which are often cut out by it. The Limestone is also above the Boulder Bed.

The speaker adduced further detailed evidence bearing on these points from Glen Tilt and Glen Elg, which all went to prove the Lewisian age of the Moine Gneisses. With regard to the rocks between the true Graphite-Schist and the Southern Highland Border, the superposition of the Quartzite on the Schist shows the succession to be a descending one, and the rocks near the Border are the lowest. This is clearly proved by the fact that a great group of rocks below anything ever occurring along this Border are brought up by a big fault, and cover a wide area stretching from the North Esk to Aberdeen, etc. These rocks, like the others, are seen to increase in crystallization as one proceeds north-westwards from the Highland Border; but the increase is much more rapid in the case of the rocks brought up by the fault.

Mr. J. F. N. Green said that he was particularly interested in the nordmarkite Boulder Bed. In Islay this had been attributed to ice on good grounds by Thomson half a century ago. In that island, where the rocks were virtually unaltered and excellent coast-sections were available, it was obvious that the bouldery beds

[1] Q. J. G. S. vol. lx (1904) pp. 423–27.
[2] *Ibid.* p. 430.

were merely lenticles occurring sporadically in a variable band of arkoses, greywacke, and dolomitic sandstone. They could not therefore be till, but should be attributed to floating ice, the bouldery patches indicating the spots where the floes unloaded.

On the mainland, in the Tayvallich peninsula, occurred the isolated Loch-na-Cille Conglomerate; and he had inferred from the Geological Survey memoir that that also was probably a lenticle in a similar band covering most of the peninsula and the eastern side of Loch Sween. On examining the Survey slides, he found that the 'quartzite' of this area was arkose. The Survey maps did not separate these felspathic rocks from pure quartzite.

The Schichallion conglomerate not only contained nordmarkite- and quartzite-boulders similar to those of Islay, but the structure and matrix appeared to be identical. The three specimens of the latter now exhibited seemed to have been originally arkose, greywacke, and dolomite-sandstone. He enquired whether the calcareous boulders might not once have been dolomite, as in the south-west. He was suspicious of the Schichallion Quartzite, in which the conglomerate seemed to be wrapped, and would like to know the average percentage of felspar in it. If it were really the arkose-band of Islay and Tayvallich, he would expect about 85 per cent. of quartz, at least in the coarser parts. In that case, the southern edge of the band was in contact with the Killiekrankie Schists, which could be traced round its western termination (as one would infer from the map) into the banded series; and schists often ran into banded series.

The SECRETARY read the following communication from Mr. E. B. BAILEY:—

'This paper will be recognized as one of the most important contributions yet made to an understanding of the Central Highlands. The Author acknowledges help from Grant Wilson's original treatment of the district, and adopts from it the commonly accepted view that the Struan Flags are something apart from the Perthshire Dalradian sequence. In this respect the Author does not follow the lead given by Mr. Barrow; but he seems to me to have confirmed beyond doubt that writer's claim regarding the stratigraphical position of the Perthshire Quartzite in relation to its Dalradian associates. With a partial knowledge of Schichallion, and a considerable acquaintance with the cognate districts of Islay, Loch Tummel, and Blair Athol, I have no hesitation in accepting every detail of the Author's stratigraphical succession. It is noteworthy that he, like myself, has been led to invert the traditional time-sequence of the Perthshire Dalradian; although, I admit, the Schichallion evidence in this direction does not seem to me convincing. As regards the discordances, which the Author very properly emphasizes, they are not only convincing, but arresting. They do not, in Schichallion, present themselves in obvious relationship to folds; and the Author is justified in adopting a cautious attitude in their interpretation. Still, it is a remarkable fact that the plane of discordance separating the Schichallion Complex from the Struan Flags corresponds precisely with what I have called, in the West, the basal thrust-plane of the Iltay Nappe.'

The AUTHOR, in answer to Dr. Flett, stated that he thought that the correlation between the Schichallion series and that

mapped by Mr. H. H. Read would only be possible after a re-examination of some of the intervening ground. He had not ruled out the possibility that the boundary-line between the Grey Schist and the Struan Flags on the eastern side of the Dalradian area was a natural one, though he regarded the western boundary as a folded line of movement. One part of the differences between himself and Mr. Barrow might be overcome by supposing that the Boulder Bed and White Limestone of the Schichallion area were usually absent in the district between Braemar and Blair Athol. This would imply that the Banded Series of the area that he had mapped was the equivalent of Mr. Barrow's Honestone Group, which it appeared to resemble.

In reply to Mr. Green, he stated that, apart from its intercalations, the Banded Series of the district now described was very easily distinguishable from any part of the Schichallion Quartzite.

17. *The* Petrology *of the* Arnage District *in* Aberdeenshire: *A* Study *of* Assimilation. By Herbert Harold Read, M.Sc., A.R.C.S., F.G.S. (Read March 14th, 1923.)

Contents.

I. Introduction.

In the Buchan, Formartine, and Strathbogie districts of Aberdeenshire, the plutonic rocks of 'Younger Granite' age include half-a-dozen large gabbro-masses the approximate positions of which are shown in fig. 1 (p. 447). These gabbros are later than the regional folding, but antedate the local Middle Old Red Sandstone. They possibly form one huge sill.

In 1914, Mr. W. R. Watt[1] described the geology of the southern part of the Huntly Mass, and announced the discovery of gabbros modified by the incorporation of sedimentary material. These endomorphic gabbro-derivatives were shown to be similar in character and origin to rocks recorded from Le Pallet (France) by Prof. A. Lacroix,[2] and from Snowbank Lake (Minnesota) by Prof. A. N. Winchell.[3] After the War it was my good fortune to revise for the Geological Survey the country around Huntly and Banff[4] (Sheets 86 & 96 of the 1-inch Geological Survey Map of Scotland), and I was then able to investigate the distribution, nature, and origin (in the Huntly Mass) of the abnormal rock-types discovered by Mr. Watt. Later, similar rocks were found in the Insch Mass.[5]

As their importance in the field increased, it was felt desirable to have some handy term for rocks resulting from the incorporation of sedimentary material in a magma, and, in 1921, the name c o n t a m i n a t e d r o c k was suggested. The term h y b r i d of

[1] 'The Geology of the Country around Huntly (Aberdeenshire)' Q. J. G. S. vol. lxx, p. 266.

[2] 'Le Gabbro du Pallet & ses Modifications' Bull. Carte Géol. France, vol. x (1898–99) pp. 341–96.

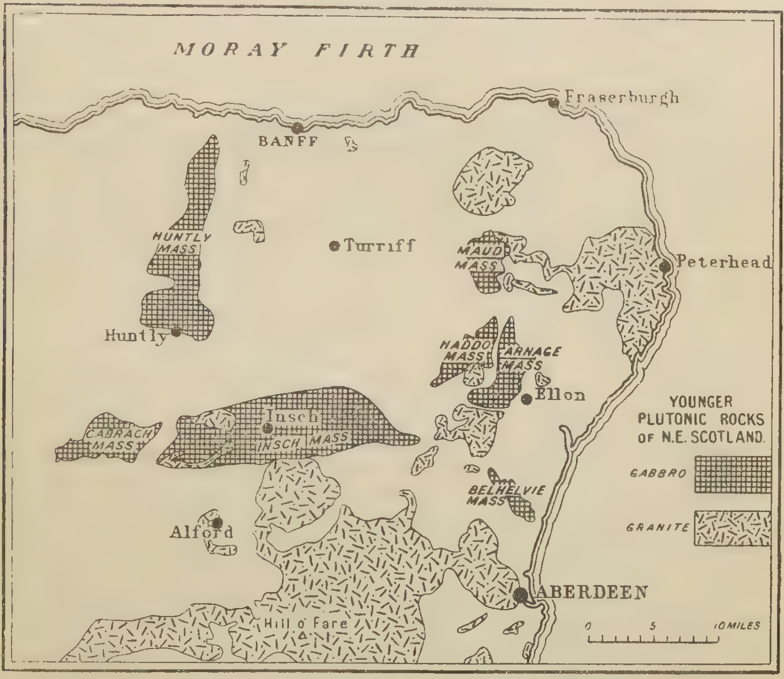
[3] 'Mineralogical & Petrographic Study of the Gabbroid Rocks of Minnesota, &c.' Amer. Geol. vol. xxvi (1900) pp. 294 *et seqq.*

[4] H. H. Read, 'The Geology of the Country round Banff, Huntly, & Turriff' (Explan. of Sheets 86 & 96) Mem. Geol. Surv. Scot. 1923. Interim reports in 'Summaries of Progress' for 1918, 1919, 1920.

[5] *Id.* 'The Contaminated Gabbro of Easter Saphock, near Old Meldrum in Aberdeenshire' Geol. Mag. vol. lviii (1921) pp. 177–83.

Dr. A. Harker was considered to have a more specialized meaning, since it has come to denote rocks formed either 'by the mixture of two magmas, or by the assimilation of a rock already consolidated by the magma of a later intrusion.'[1] Perhaps, too, I was influenced by the emphasis laid by Dr. Harker on the barrenness of these hybrids in their wider petrogenetic aspect, and so endeavoured to remove contaminated rocks from these sterile relatives.

Fig. 1.



In the Huntly and Insch masses the contaminated rocks, although occurring at many localities, covered in no place much more ground than a square mile; besides, they did not appear to throw any certain light upon the petrogenetic problem. But in the third of the masses to be investigated—that of Arnage and the subject of this communication—it is gratifying to find that contaminated rocks form the main visible part of the intrusion, and are seen over an area of about 16 square miles. At Arnage the scale of the phenomena is large enough, and the stage reached in contamination is sufficiently far advanced, to warrant, I believe, certain speculations as to the relation of contamination to the origin of the diversity of igneous rocks.

[1] A. Holmes, 'The Nomenclature of Petrology' 1920, p. 121.

II. Previous Work.

Before this investigation no modern work had been done on the Arnage Mass. This mass forms part of the 'diorite' of J. S. Grant Wilson,[1] as described in the Survey Memoir of 1886. The excellent norites of Arnage have been mentioned by H. Rosenbusch[2] and briefly described and figured by Dr. A. Harker.[3] Sir Jethro Teall[4] foreshadowed the main feature of the Arnage Mass, when in 1896 he discussed certain cordierite-bearing rocks of Scotland. Of one specimen from Little Arnage he said:—'it is evidently a compound rock due to the superposition of igneous upon metamorphic material' (*op. cit.* p. 37).

III. The Country-Rocks.

The rocks into which the Arnage Mass is intruded, and which supply the material for contamination of the original magma, belong to two main groups:—

(i) A series of andalusite-cordierite-schists and felspathic quartzites, with quite subordinate impure limestone-bands, occurring west, north, and north-east of the igneous and contaminated rocks. (See fig. 2, p. 452.)

(ii) A series of biotite-gneisses and subordinate hornblende-schists, occurring south-east of the igneous and contaminated rocks. (See fig. 2, p. 452.)

The first group, occurring north of a line drawn from Ardlethen to Berefold, may be considered as made up of a western argillaceous and an eastern quartzose sub-group. On the west the dominant rock-type is an andalusite-cordierite-schist with subordinate quartzite, while on the east quartzites with subordinate andalusite-schists occur. The western andalusite-schists are the north-eastern extension of a series of andalusite-schists well seen in the Ythan Valley between Fyvie and Methlick; these have been called the Fyvie Schists,[5] and lithologically they are exactly similar to another group of andalusite-schists—those of Boyndie Bay[6]—on the Banffshire coast. It is extremely probable that these two groups are the same, and occur on opposite sides of a central synclinal area of Macduff Slates.[7]

The eastern quartzose sub-group was separated out by J. S. Grant Wilson,[8] and to it was assigned a stratigraphical status

[1] 'Explanation of Sheet 87' Mem. Geol. Surv. Scot. 1886, p. 17.

[2] 'Mikroskopische Physiographie' 4th ed. vol. ii, pt. 1 (1907) p. 349.

[3] 'Petrology for Students' 5th ed. (1919) pp. 77–78 & fig. 23 B.

[4] 'Explanation of Sheet 75' Mem. Geol. Surv. Scot. 1896, pp. 37, 38.

[5] H. H. Read, 'The Geology of the Country round Banff, Huntly, & Turriff' (Explan. of Sheets 86 & 96) Mem. Geol. Surv. Scot. 1923, Chap. iv.

[6] *Id. ibid.* and 'The Banffshire Coast-Section of the Highland Schists', App. I to 'Summary of Progress of the Geological Survey for 1920' Mem. Geol. Surv. 1921, p. 76.

[7] *Id.* 'The Geology of the Country round Banff, Huntly, & Turriff' (Explan. of Sheets 86 & 96) Mem. Geol. Surv. Scot. 1923, Chap. iv.

[8] 'Explanation of Sheet 87' Mem. Geol. Surv. Scot. 1886, pp. 9–11. Map, Sheet 87.

equal to that of the andalusite-schists; but, since beds of andalusite-schist occur throughout this eastern sub-group and beds of quartzite throughout the western andalusite-schist, it is sufficient for the present purpose to consider these two sub-groups as forming one—that of the Fyvie Series, although it is possible that in this extended Fyvie Series there may be included the equivalents of more than the Boyndie Bay Group of the Banffshire coast-section.

The main rock of the Fyvie Series west of the Arnage Mass is a nodular andalusite-cordierite-schist, well exposed along the Ythan gorge between Methlick and Gight. It is a greyish, rather micaceous rock from the weathered surfaces of which project large crystals of andalusite measuring as much as 2 cm. in length. In slices, the ground-mass of the rock is seen to be composed of coarse quartz-grains, biotite-flakes, and rather large white micas; in this base are porphyroblastic masses of both cordierite and andalusite, the former occurring as dirty greenish-yellow irregular patches, the latter as large granular crystals. Both include much ground-mass material, and the cordierite holds also chlorite in large laths. Occasionally, small brown staurolites occur between the large andalusite porphyroblasts.

The andalusite-schist of the Boyndie Bay Group has been analysed by Mr. E. G. Radley, and, for reasons already given, this analysis may be taken to represent that of the normal andalusite-schist of the Fyvie Series. This analysis, and one of the Macduff Slate into which both Fyvie and Boyndie Bay Groups pass, are set forth in Table I, Analyses I & II, p. 450. They represent argillaceous rocks, differing from that which Prof. V. M. Goldschmidt[1] has styled the typical clay-rock (Anal. T, Table I), chiefly in the relative amounts of the alkalies. The Scottish rocks are much richer in soda than is Prof. Goldschmidt's type.

The felspathic quartzites of the eastern division show small felspars and greasy quartzes in a scarce fine-grained base. In slice, pebbles, often rounded, of quartz, orthoclase, and scarcer oligoclase are set in a scanty ground-mass of small biotite-flakes, quartz-grains, and a little dirty decomposed felspathic substance. Others of these gritty rocks approach the greywacke type; these are finer in grain, and consist of small, often angular grains of quartz, oligoclase, and potash-felspar in a ground-mass of biotite, muscovite, quartz, felspar, and magnetite.

The quartzites vary from fairly pure quartz-rocks to felspathic quartzites containing some 20 per cent. of felspar, the purer types being more common around the Arnage Mass. The chemical composition of an average quartzite concerned in contamination may be taken as somewhat like that of the Cullen Quartzite[2] of Banffshire, an analysis of which is given in Table I, Analysis III,

[1] 'Die Kontaktmetamorphose im Kristianiagebiet' Videnskap. Skrift. I, Mat.-naturv. Klasse, 1911, No. 1, p. 16.

[2] H. H. Read, 'The Banffshire Coast-Section of the Highland Schists' App. I to 'Summary of Progress for 1920' Mem. Geol. Surv. 1921, p. 72.

below. The Arnage rock is doubtless richer in magnesia than the Cullen Quartzite.

The third and quite subordinate type of sediment of the Fyvie Series is an impure sandy limestone formerly quarried at Auchnagatt, Michaelmuir, Auchedly, and Ardlethen, where it forms bands, at their broadest less than 90 yards across, in the andalusite-schists and quartzites. One of the purest of these bands is that formerly quarried at Quarryhead, three-quarters of a mile north-west of Auchnagatt Station. In slice, it is seen to consist chiefly of large grains of calcite, together with scarce quartz, alkali-felspar, pyroxene, apatite, and magnetite-grains. By reason of their small bulk these limestones play practically no recognizable part in the contamination-phenomena.

Table I.—Analyses of Sediments like those concerned in Contamination.

	I.	II.	T.	III.	IV.
SiO_2	53·98	58·47	63	86·12	67·23
TiO_2	1·15	1·30	...	0·39	0·86
Al_2O_3	22·77	18·27	20	5·72	13·38
Fe_2O_3	2·33	1·66	7	0·75	1·23
FeO	7·22	6·49		0·61	4·88
MnO	0·18	0·25	...	0·17	0·16
(CoNi)O	nt. fd.	? trace	...	nt. fd.	nt. fd.
BaO	0·12	0·05	...	nt. fd.	0·04
CaO	1·97	0·78	1	0·85	2·08
MgO	3·16	2·64	2	0·04	4·33
K_2O	2·97	2·84	6	3·15	2·92
Na_2O	2·14	2·46	1	1·44	1·92
Li_2O	nt. fd.	nt. fd.	...	nt. fd.	nt. fd.
H_2O at 105° C.	0·10	0·09	...	0·09	0·05
H_2O above 105° C.	1·87	3·37	...	0·27	1·03
P_2O_5	0·17	0·15	...	0·03	0·15
FeS_2	nt. fd.	0·60	...	nt. fd.	0·01
Fe_7S_8	nt. fd.	0·72	...	(ZrO_2=·03)	0·07
CO_2	0·04	0·08	...	0·42	0·11
Totals	100·17	100·22	100	100·08	100·45

I. Andalusite-schist of the Boyndie Bay Group, Whitehills, Banffshire (compare Fyvie Andalusite-Schist). Anal. E. G. Radley. 'Summary of Progress for 1921' Mem. Geol. Surv. 1922, p. 108.

II. Macduff Slate, 2 miles east of Macduff (Banffshire). Anal. E. G. Radley. 'Summary of Progress for 1921' Mem. Geol. Surv. 1922, p. 108.

T. Prof. V. M. Goldschmidt's typical 'Marine Tongestein': see 'Die Kontakt-Metamorphose im Kristianiagebiet' Vidensk. Skrift. I, Mat.-naturv. Klasse, 1911, No. 1, p. 16.

III. Cullen Quartzite, Craig Head, Banffshire (compare Fyvie Quartzite). Anal. E. G. Radley. 'Summary of Progress for 1921' Mem. Geol. Surv. 1922, p. 108.

IV. Cowhythe Gneiss, Strathmarchin Bay, Portsoy, Banffshire (compare Ellon Gneiss). Anal. E. G. Radley. 'Summary of Progress for 1921' Mem. Geol. Surv. 1922, p. 108.

The second series of metamorphic schists concerned in the contamination of the Arnage Mass occurs south-east of the igneous rocks. This group of schists is well developed around Ellon, and

for the purposes of this communication they may conveniently be styled the Ellon Series.[1] Two main rock-types make up this series: (1) dominant biotite-gneisses, schists, and granulites, and (2) subordinate hornblende-schists.

The first type is seen, among other localities, in the southern bank of the Ythan at Esslemont House, at Craigs of Auchterellon near Ellon Station, at Craighall, and in the Braes o' Waterton, 1 mile east of Ellon. The strike of the foliation-planes along the Ythan is north-east to south-west, or north-north-east to south-south-west; dips are variable, and mainly low, on both sides of these lines.

The rock-varieties of this type are all greyish granulitic schistose or gneissic rocks composed mainly of quartz, felspar, and biotite; garnet and cordierite are rare. The granulitic variety shows in slice quartz-grains as the dominant component, together with a considerable amount of unoriented biotite (pleochroic from pale yellow to deep brown) and a fair quantity of felspar; clouded orthoclase is the chief species of felspar, less common are microcline and oligoclase; zircon is accessory: the rock is a quartz-felspar-granulite. In the gneissose varieties the same minerals occur, but here the dominant felspar is oligoclase, which is, in some specimens, almost as abundant as the quartz; garnet in scarce small crystals is sometimes seen in these rocks. The third main variety is a shaly biotite-schist, with abundant orientated biotite and rarer muscovite, separated by bands of granulitic quartz with scarce plagioclase-grains. From the Braes o' Waterton comes a cordierite-biotite-schist, in which, in addition to the usual minerals of these rocks, occur streaks of cordierite now replaced by micaceous decomposition-products. All the sedimentary rock-types of the Ellon Series are streaked with quartz-lenticles and stringers.

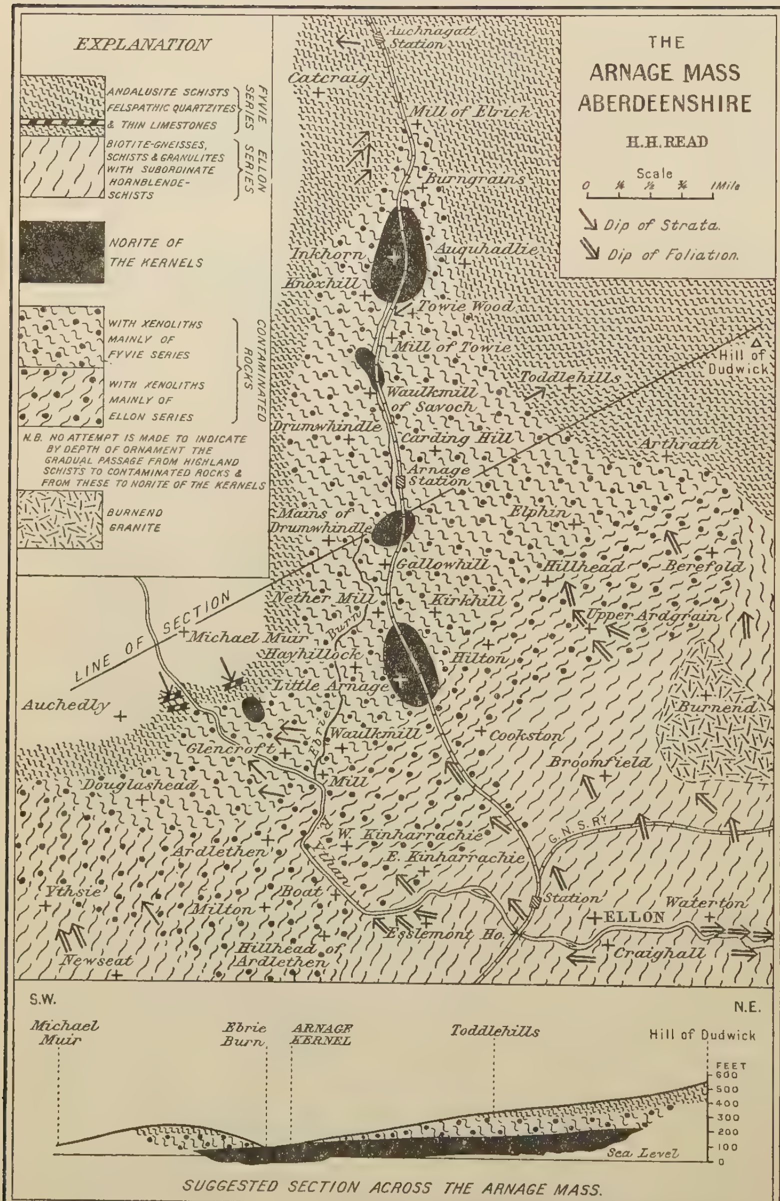
The three main types are found in intimate varying association over the ground south-east of the igneous and contaminated rocks (see fig. 2, p. 452). In its mineral-content the Ellon biotite-gneiss is very like the oligoclase-biotite-gneiss of the Cowhythe Group[2] of the Banffshire coast, and the analysis of this gneiss (Analysis IV, Table I, p. 450) may be taken to represent one common variety of the sedimentary types of the Ellon Series.

The hornblendic rocks of the Ellon Series can be studied in their unaltered state in the Braes o' Waterton. The rock is a well-foliated dark-green hornblende-schist, which in slice is seen to be made up of stout hornblende-prisms, pleochroic in shades of yellow and green, with a subordinate amount of quartz and felspar. The hornblende-prisms are collected into bands separated by layers of quartz, felspar, and smaller and scarcer hornblende-grains. The felspar is quite clear and recrystallized; it varies from

[1] See J. S. Grant Wilson, 'Explanation of Sheet 87' Mem. Geol. Surv. Scot. 1886, pp. 7–9.

[2] H. H. Read, App. I to 'Summary of Progress for 1920' Mem. Geol. Surv. 1921, p. 75.

Fig. 2.


THE
ARNAGE MASS
ABERDEENSHIRE
H.H. READ
Scale
0 ¼ ½ ¾ 1 Mile
Dip of Strata.
Dip of Foliation.
EXPLANATION
ANDALUSITE SCHISTS
FELSPATHIC QUARTZITES
& THIN LIMESTONES
FYVIE SERIES
BIOTITE-GNEISSES, SCHISTS & GRANULITES WITH SUBORDINATE HORNBLENDE-SCHISTS
ELLON SERIES
NORITE OF THE KERNELS
WITH XENOLITHS MAINLY OF FYVIE SERIES
WITH XENOLITHS MAINLY OF ELLON SERIES
CONTAMINATED ROCKS
N.B. NO ATTEMPT IS MADE TO INDICATE BY DEPTH OF ORNAMENT THE GRADUAL PASSAGE FROM HIGHLAND SCHISTS TO CONTAMINATED ROCKS & FROM THESE TO NORITE OF THE KERNELS
BURNEND GRANITE
Auchnagatt Station
Catcraig
Mill of Elrick
Burngrains
Inkhorn
Auquhadlie
Knoxhill
Towie Wood
Mill of Towie
Hill of Dudwick
Toddlehills
Waulkmill of Savoch
Drumwhindle
Carding Hill
Arthrath
Arnage Station
Mains of Drumwhindle
Elphin
Gallowhill
Hillhead
Berefold
Nether Mill
Kirkhill
Upper Ardgrain
LINE OF SECTION
Michael Muir
Ebrie Burn
Hayhillock
Hilton
Little Arnage
Auchedly
Burnend
Waulkmill
Cookston
Glencroft
Broomfield
Mill
Douglashead
G.N.S. RY.
W. Kinharrachie
Ardlethen
E. Kinharrachie
Ythsie
Boat
Station
Waterton
Milton
Ythan
ELLON
Esslemont Ho.
Hillhead of Ardlethen
Craighall
Newseat
S.W.
N.E.
Michael Muir
Ebrie Burn
ARNAGE KERNEL
Toddlehills
Hill of Dudwick
FEET
600
500
400
300
200
100
0
Sea Level
SUGGESTED SECTION ACROSS THE ARNAGE MASS.

andesine to labradorite. A few grains of black iron-oxide complete the rock.

In summary, then, the contaminators of the Arnage Mass are of four petrographic types:—

1. Andalusite-cordierite-schists.
2. Felspathic quartzites.
3. Biotite-oligoclase-gneisses and biotite-schists.
4. Hornblende-schists.

The contact-metamorphism of each of these rock-types is described in § VI, pp. 473–78.

IV. The Norite Sheet.

Before considering the rocks to which the name contaminated is here applied, we may deal with a very striking feature of the Arnage district, and that is the norite sheet which underlies the zone of contaminated rocks and into which they pass downwards (see fig. 2, section, p. 452). H. Rosenbusch [1] said, concerning the norite. that it was an extraordinarily beautiful representative of its class. Dr. A. Harker [2] has figured a typical norite from Towie Wood. In the 1886 Geological Survey Memoir the norite (and the contaminated rocks) were all designated 'diorite', though, it is true, the variations of the 'diorite' were there noted as considerable.[3]

Distribution.—The distribution of the norite is a striking one (see fig. 2). The country is of low relief, but even so it is fairly obvious that the norite is seen at slightly lower levels than the contaminated rocks. It forms small areas exposed by the removal of the overlying contaminated-rock zone, and surrounded by these contaminated rocks. If erosion had proceeded to a slightly less extent, it is probable that none of the norite would have been exposed. These norite outcrops do not represent cupolas—they are best regarded as inliers, as it were, of a somewhat level-topped norite sheet (see fig. 2, section, p. 452); they may be called, for the sake of simplicity, kernels.

Five kernels have been recognized; they are, from north to south, those of Inkhorn, Waulkmill of Savoch, Arnage, Little Arnage, and Glencroft.

The Inkhorn kernel has a longer axis three-quarters of a mile long; its breadth is probably less than half a mile. The rock of this kernel is well exposed in the railway-cutting north and south of Mill of Inkhorn, and the limits of the norite can be fixed at both ends, for there is a somewhat abrupt passage into contaminated rocks.

[1] 'Mikroskopische Physiographie' 4th ed. vol. ii, pt. 1 (1907) p. 349.

[2] 'Petrology for Students' 5th ed. (1919) pp. 77–78 & fig. 23 B.

[3] J. S. Grant Wilson, 'Explanation of Sheet 87' Mem. Geol. Surv. Scot. 1886, p. 17.

The Waulkmill of Savoch kernel is small, being less than a third of a mile long, and is situated astride the Ebrie Burn. Good examples of the rock of this kernel are seen in the railway-cutting at Waulkmill of Savoch, near which locality, too, the associated contaminated rocks may be studied.

The third kernel, that of Arnage, occurs south of Arnage Station; normal norite can be examined in the railway-cutting, and its contaminated associates observed with some clearness on the brae east of the Ebrie Burn, east of Mains of Drumwhindle; this kernel is about a third of a mile in greatest diameter.

The Little Arnage kernel is found farther south again, and is exposed also in the railway-cutting; its length is about two-thirds of a mile, and it exhibits good contamination phenomena on the south.

The last kernel, that of Glencroft, on the northern bank of the Ythan, is somewhat unsatisfactory; here is an abundance of large blocks of norite, some of which are probably in place. The argument, however, is not affected, even if the Glencroft kernel be neglected.

Taken together, the norite kernels cover an area of well under one square mile.

Petrography.—The norite is a homogeneous fairly coarse rock, which weathers either into rude spheroidal masses, or into rounded knob-forms coated with a thin skin of decomposed material. In the kernels the rock appears thoroughly uniform. With a lens, felspar, a dark mineral (hypersthene), and scarce biotite-plates can be recognized. The rock is quite fresh.

About twenty slices of the norite have been cut. All the kernels, with the exception of the doubtful Glencroft one, show exactly similar norite. The rock is composed almost entirely of labradorite and hypersthene (see fig. 3, p. 455); quite subordinate are hornblende, biotite, diallage, quartz, iron-oxide, and apatite.

The felspar is fresh, and forms subhedral or euhedral prisms, often 1·25 mm. long: its sign is positive; albite and rare pericline twinning is seen; its optical properties indicate that it is a labradorite of the composition $Ab_{35}\ An_{65}$. Sometimes the interiors of the crystals are slightly more basic than the exteriors. The felspar often includes multitudes of minute brownish-red plates which have apparently no definite orientation with regard to their host, although among themselves they are arranged on three planes.

Hypersthene forms prismatic crystals, often 1 mm. long by 0·5 mm. wide. Cross-sections show the dominance of pinacoids over prism faces, and the usual prismatic cleavage. The pleochroism is striking—𝔞 pale pink, 𝔟 pale yellow-green, 𝔠 pale green; the sign is negative. The mineral usually is very thoroughly schillerized. An intergrowth on a minute scale with a monoclinic pyroxene is occasionally seen. Often the hypersthene-crystals exhibit the synneusis structure of Vogt, being collected into swarms and

then, in the Arnage case, cemented by black iron-oxide. The hypersthene alters into pale-green fibrous hornblende. The times of finishing of crystallization of hypersthene and felspar appear to be about the same, neither mineral being strictly euhedral.

In some slices diallage occurs in small amount, perhaps two plates being seen in a slice of average dimensions. It usually forms large, much-schillerized, ophitic plates enclosing small felspars and hypersthene, and is edged by hornblende.

The hornblende is pleochroic as follows:—$\mathfrak{a}$ pale yellow-green, $\mathfrak{b}$ deep brown, $\mathfrak{c}$ green-brown, with the absorption $\mathfrak{c}=\mathfrak{b}>\mathfrak{a}$, and $C:\mathfrak{c}$ = about 10°. It forms an edging to hypersthene or diallage, or builds larger plates with hypersthene kernels, these

Fig. 3.—*Norite of the sheet.*

A *B* *C*

A = Labradorite (Lab.) and hypersthene (Hy.), with scarce biotite (Bi.), quartz (Qz.), and iron-oxide. × 23 (see p. 454).

B = Illustration of the reaction series; hypersthene (Hy.), hornblende (Ho.), biotite (Bi.), and quartz (Qz.). Solid black represents iron-oxide. × 46 (see p. 456).

C = Illustration of the reaction series; olivine (Ol.), hypersthene (Hy.), hornblende (Ho.), and biotite (Bi.). × 46 (see p. 456).

kernels having a ragged edge against the enclosing hornblende (see fig. 3). In its turn, too, the hornblende is often bordered by yellow to deep-red biotite, with which are associated large irregular grains of black iron-oxide. Micropegmatitic intergrowths of hornblende, biotite, and quartz are noted (see fig. 3).

Apatite occurs in accessory prisms which sometimes reach 1 mm. in length; black iron-oxide is always present, and usually associated with the biotite.

Quartz, though widespread, is not abundant; usually it forms interstitial areas between felspar prisms, sometimes it is in rounded grains between which biotite may occur, or takes part in biotite-hornblende-quartz intergrowths. No sign of micropegmatitic intergrowths with felspar has been noted.

The hypersthene, hornblende, and biotite of the Arnage norite provide an excellent example of what Dr. N. L. Bowen[1] has recently called a discontinuous reaction series. This series depends upon reaction between the liquid and crystal phases of a solidifying melt, a reaction moving so that an early formed member of the series tends to change over into a later member. A familiar example, and one that has been experimentally investigated,[2] is that of the 'reaction-rims' of rhombic pyroxene around olivine. It is probable that crystallization in the Arnage norite-magma began with the formation of olivine, which, as the temperature fell, was attacked by the liquid to produce hypersthene, this in turn to produce hornblende, and the hornblende, biotite; concurrently, of course, the bulk of the melt had been lessening, and its composition altering by the crystallization of plagioclase, until, when the last of the biotite was being formed by reaction, the silica-residuum crystallized as quartz, often in micropegmatitic intergrowths with the mica. As is seen immediately, the norite of the Glencroft kernel contains olivine, always armoured by hypersthene, and so in these norites there is a good example of the reaction series: olivine—hypersthene—hornblende—biotite.

The rock of the supposed Glencroft kernel differs from the rest of the kernel-norites by containing olivine; in its other constituent minerals it is exactly like the normal norite just described. The olivine occurs in abundant rounded resorbed grains, always surrounded by a coating (sometimes exceedingly thin) of hypersthene. The reaction series: olivine—hypersthene—hornblende—biotite is well seen in this rock.

A similar rock, an olivine-norite, occurs as a small patch in the contaminated rocks, in the coppice 300 yards south of Mill of Kinharrachie. The reaction series described above is especially well developed in this example (fig. 3).

Chemical composition.—By the kind permission of the Director of the Geological Survey, an analysis of the norite of the Arnage Mass has been made in the Survey Laboratory by Mr. E. G. Radley, to whom my thanks are due. In Table II (p. 457) this and other analyses of gabbro are set forth. The most striking feature of the Arnage norite is its richness in magnesia compared with the other Aberdeenshire gabbros, or with Prof. R. A. Daly's average norite, or with the average of 44 norites enumerated in Dr. H. S. Washington's tables.

[1] 'The Reaction Principle in Petrogenesis' Journal of Geology, vol. xxx (1922) p. 183.

[2] Olaf Andersen, 'The System Anorthite-Forsterite-Silica' Amer. Journ. Sci. ser. 4, vol. xxxix (1915) p. 407.

TABLE II.—THE NORITE AND OTHER GABBROS.

	V.	B.	C.	D.	E.
SiO_2	52·04	47·52	50·16	50·23	48·84
TiO_2	0·66	3·06	1·64	1·15	1·35
Al_2O_3	16·31	15·65	18·51	16·40	15·90
Fe_2O_3	0·06	0·75	1·88	2·39	5·23
Cr_2O_3	0·05	...	...	...	...
V_2O_3	0·01	...	...	...	...
FeO	7·98	10·90	9·29	7·64	6·30
MnO	0·14	0·27	0·14	0·12	0·29
(CoNi)O	nt. fd.	...	...	...	...
BaO	trace	...	...	...	...
CaO	7·24	10·83	7·90	8·92	9·15
MgO	11·70	6·35	5·97	8·54	6·38
K_2O	0·89	0·56	0·80	0·81	1·46
Na_2O	1·82	2·55	2·72	2·54	3·05
Li_2O	trace	...	...	...	...
H_2O at 105° C.	0·06	0·63	0·76	...	1·60
H_2O above 105° C.	0·51			0·68	
P_2O_5	0·08	0·28	0·23	0·22	0·45
FeS_2	0·02	...	...	...	...
Fe_7S_8	0·51	...	...	...	...
CO_2	0·46	...	...	...	...
Totals	100·54	99·35	100·00	99·64	100·00

V. Norite of the Arnage Mass. Railway-cutting, 600 yards south of Mill of Inkhorn, Arnage, Ellon. Anal. E. G. Radley.

B. Average for chief oxides of six gabbros of the Huntly and Insch Masses: see 'Explan. of Sheets 86 & 96' Mem. Geol. Surv. Scot. 1923, Chap. VI.

C. Average of all norite (seven analyses); R. A. Daly, 'Igneous Rocks & their Origin' 1914, p. 27.

D. Average of 44 rocks, designated norite, in Dr. H. S. Washington's 'Chemical Analyses of Igneous Rocks' U.S. Geol. Surv. Professional Paper 99, 1917.

E. 'Primary basaltic magma' of R. A. Daly, 'Igneous Rocks & their Origin' 1914, p. 315.

V. THE CONTAMINATED ROCKS.

Introduction.—Between the kernel-norites and the true country-rocks is a zone several miles wide made up of the rocks here styled contaminated. This zone is believed to lie above the norite-sheet exposed in the kernels (see fig. 2, p. 452), and represents the modification of the initial magma by incorporation of country-rock. The chief characteristics of the contaminated rocks are four, namely:—

(i) They are extremely rich in xenoliths.

(ii) They are variable in grain and type-distribution.

(iii) They have a more or less pronounced fluxional structure.

(iv) They vary in composition from gabbroic rocks to rocks of granitic type, and contain minerals—the chief of which are cordierite, spinel, and garnet—usually considered abnormal in igneous rocks.

The area covered by these contaminated rocks at Arnage is about 16 square miles. Their margins against the country-rocks

shown in fig. 2 have been plotted where no igneous material was discernible in these; but there is a gradual passage from country-rock to contaminated rock, and from this to norite. No clearer example of assimilation could be desired.

Since these contaminated rocks are extraordinarily prone to rapid variation, it is a matter of some difficulty to attempt their description, but certain broad types and distributions can be recognized. These are:—

(A) A type which in composition approaches that of the norite; this type occurs in small patches kneaded in among the more contaminated types, and may be called the Gabbro Type.

(B) The most widespread type, occurring typically north of a line drawn from Ardlethen to Cookston (see fig. 2, p. 452), and consisting of varying associations of quartz, cordierite, plagioclase, alkali-felspar, and biotite, with rarer garnet, spinel, and tourmaline. This type represents the result of the modification of the initial magma by quartzose and argillaceous sediments of the Fyvie Series, and biotite-schists of the Ellon Series. It will be here called the Arnage Type.

(C) A dioritic type seen between the Little Arnage kernel and the River Ythan, and produced by the contamination of the initial magma with hornblende-schists of the Ellon Series; this type, from its splendid exposures on the Kinharrachie estate, may be called the Kinharrachie Type.

(D) The rocks occurring south of the Ythan around Ardlethen are dealt with separately in this description, since here (associated with the other types) is the best development of the granitic end-product of contamination. This granitic end-product may be called the Ardlethen Type: its importance from the petrogenetic standpoint needs no emphasis.

These four types, with their distribution and petrography, will now be discussed in order.

(A) The Gabbro Type of Contaminated Rock.

These rocks appear to provide transitions between the norite and the chief contaminated rock, that of Arnage Type. They occur away from the kernels, as small patches intimately associated with the contaminated rocks into which they pass. As an example, we may take a small knob situated east of the Ebrie Burn, 500 yards south of Nether Mill, where, from a rock-face only a few square yards in area, there can be collected homogeneous gabbro types and variable contaminated rocks crowded with xenoliths. Other good localities for these little-modified types are in the wood east of Waulkmill of Savoch, or at Mill of Elrick at the northern end of the Arnage Mass.

In itself, this gabbro type is variable, in sharp contrast with the strictly uniform norite. Two chief varieties are noted: the first of these can be seen in the wood east of Waulkmill of Savoch, or at the Ebrie side 300 yards south-east of Mains of Drumwhindle, and is a coarse grey rock showing large plates of biotite. In slice it is found to be a quartz-gabbro made up of diallage, hypersthene, acid labradorite, and quartz. The quartz is much more abundant than

in the norite, and forms large patchy aggregates of grains; commoner, too, are the biotite and hornblende.

The second variety of this type is fine-grained, and is found, associated with much-contaminated rocks, in the Nether Mill knob, at Mill of Elrick, or in the wood east of Waulkmill of Savoch. In slice the structure is granular, and the rock approaches a beerbachite. Not only is the structure different from that of the norite, but the pyroxene is now mainly monoclinic. The rock consists of subhedral prisms of acid labradorite, granular pyroxenes, brown-green hornblende, biotite, quartz, and magnetite. Like their more contaminated associates, these quartz-gabbros have often a fairly well-defined fluxional structure.

There also occur, at Towie Wood and elsewhere, a few small patches of contaminated rock which are like the Arnage Type to be next described, but show a small amount of hypersthene, in addition to much quartz, acid labradorite, biotite, often hornblende, and rarely cordierite. These patches are closely associated with contaminated rocks of the Arnage Type, into which they pass gradually by loss of hypersthene and increase of cordierite.

In all these gabbro-types the plagioclase is richer in the albite-molecule than is that of the norite.

(B) Quartz-Biotite-Felspar-Cordierite-Rocks, or the Arnage Type.

Mode of occurrence.—As already stated, this type of contaminated rock is found mainly north of a line drawn from Mill of Kinharrachie to the southern end of the Little Arnage kernel, and thence to Cookston; it is the most widespread of the contaminated types, and, in the whole Arnage Mass, occurs over an area of about 13 square miles. In the field the rocks of this type are extremely variable in structure, and in the relative proportions of their component minerals; but all varieties agree in showing partly digested sedimentary xenoliths, which are often sufficiently abundant to impart to weathered surfaces of the rock a conglomeratic aspect. These xenoliths are described on pp. 473–78; here only the contaminated matrix is dealt with. Anywhere outside the kernels this type and its xenoliths can be studied, but especially beautiful phenomena can be seen at the following localities:—

(1) Towie Wood, at the southern end of the Inkhorn kernel, a mile and a quarter north of Arnage Station.—In the ground immediately east of the railway, and especially in a rocky knoll rising out of a peaty flat there, the contaminated rocks enclose abundant xenoliths of hornfelsed quartzite and blue argillaceous hornfels. The bedding of the larger of these hornfels-blocks has a constant dip over the area exposed, pointing to roof-contamination; they are described in detail on pp. 474–78. Often the contaminated rock forms a lit-par-lit complex with the argillaceous hornfels, and all stages of mixture of hornfels and magmatic rock can be observed: the first stage consists of the

veining of large hornfels-blocks by threads of contaminated rock; a second of a lit-par-lit complex, with perhaps equal amounts of sediment and magmatic rock; and a final stage of a somewhat homogeneous rock, with only small ghosts of xenoliths left. A good deal of quartz occurs as knots, nests, and stringers, as if it were rejected in the contamination-process.

(2) Wood, east of Waulkmill of Savoch.—Here, in addition to the beerbachitic gabbro and the quartz-gabbro already described from this locality, there are several varieties of quartz-cordierite-biotite-felspar-rock, with many ghosts of xenoliths and considerable quartz-nests. Farther south along the Ebrie Burn, similar xenolithic garnetiferous contaminated rocks are seen.

(3) Carding Hill, a third of a mile north-east of Arnage Station.—This conspicuous hill provides very good exposures of garnetiferous xenolithic contaminated rocks, rich in biotite; fluxional structures appear to run north-east and south-west.

(4) Arnage Station Quarry, 300 yards south-west of Arnage Station.—Very beautiful and fresh specimens of garnetiferous contaminated rocks are obtainable here; they show a well-marked fluxional structure running north-north-east and south-south-west; there seems to have been a very thorough kneading of matrix and xenoliths, and thus the latter tend to occur as wisps, films, or pulled-out 'ghosts.'

(5) Gallow Hill, between the railway and the Ebrie Burn, two-thirds of a mile south-south-west of Arnage Station.—Many varieties of contaminated rocks are exposed here, some fine-grained, some extremely coarse, some with a multitude of xenoliths, some practically homogeneous. There is often a tendency to banding or fluxional structure, but no definite orientation was observed.

(6) Kirk Hill and Hilton Croft Quarry, between the Arnage and Little Arnage kernels.—Good exposures of coarse biotitic garnetiferous contaminated rocks, and many other varieties, one of which is porphyritic, are seen at these localities. Fine blue hornfelses can be collected in Hilton Croft Quarry.

(7) The Ardgrain-Elphin section, $2\frac{1}{2}$ miles north of Ellon.—On the rough ground along the road leading from Upper and Nether Ardgrain to Elphin are abundant rock-exposures which show a perfect gradation from Ellon gneiss on the south-east into contaminated rock on the north-west. Starting at the Ellon gneiss and going north-north-westwards, we find first gneisses, delicately lit-par-lit injected and veined by threads of igneous contaminated rock, exposed south of Upper Ardgrain. These igneous injections increase in abundance north-westwards, so that at the farm itself there are good massive contaminated rocks with xenoliths of hornfelsed gneiss. Similar rocks are seen on the Hill of Ardgrain north-east of the farm. On a line north-north-west from the farm to the top of Elphin Hill the rocks exposed are coarse garnetiferous mixtures, with abundant hornfels xenoliths; these xenoliths preserve

a constant bedding-dip to the north-west, and the dip of the fluxion in the magmatic rocks is in the same direction. On the top of Elphin Hill the contaminated rock is one typical of the Arnage Type; it holds small xenoliths of blue hornfels, and is nested with much quartz. The strike of the fluxion is still north-east and south-west.

(8) Hayhillock knob, half a mile south-south-west of Hayhillock.—At this locality are found associated excellent examples of the Arnage Type of felspar-biotite-quartz-cordierite-rock and hornblendic rocks of the Kinharrachie Type. All these rocks are patchy and streaky, with a fluxion running north-east and south-west; xenoliths of quartzite and argillaceous schists are abundant; the smaller xenoliths, chiefly of shaly material, are aligned with the fluxion, which curves in treacly bands around the larger xenoliths. There are abundant nests of white quartz measuring up to 2 inches in diameter.

From the field evidence there can be little doubt that the contaminators of the initial magma which provide the Arnage Type are andalusite-schist and quartzite of the Fyvie Series and biotite-gneisses and schists of the Ellon Series. From certain evidence given in § VI it appears that the most important contaminator for this Arnage Type is an argillaceous schist (see p. 474).

Petrography.—In hand-specimens the rocks of this type are coarse-grained, greyish or bluish, and show biotite, cordierite, quartz, and felspar. Large pink garnets are usually scattered through the rock; xenoliths are seen in all stages of digestion, and there can be no doubt that the matrix in which they are held was a magmatic rock. In a weathered condition the garnetiferous rocks of this type resemble a plum-pudding in appearance, for the felspars take on a rich brown colour, and serve as a suitable background for black biotites and red garnets.

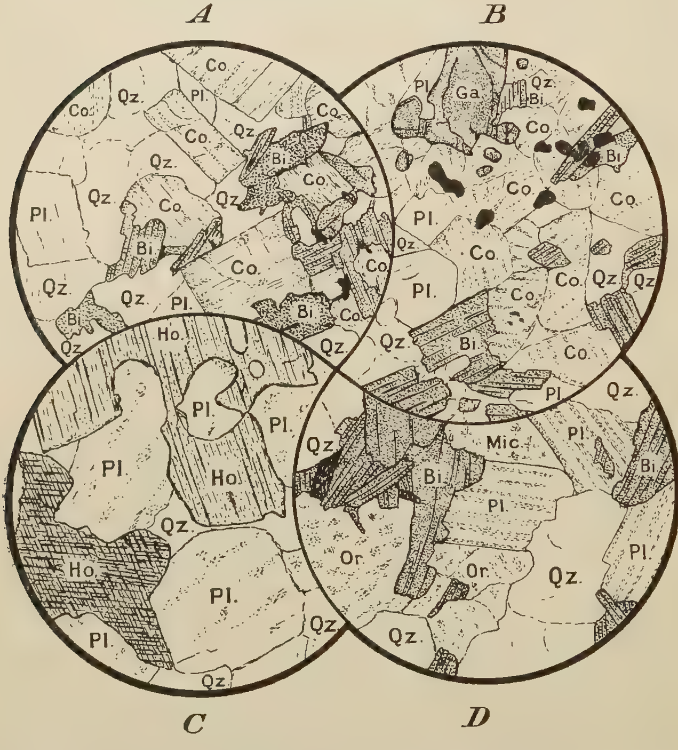
The chief mineral constituents of the Arnage Type are quartz, cordierite, felspars (oligoclase-andesine, soda-microcline, and rare orthoclase), and biotite; less common, although of widespread occurrence, are garnet, spinel, and tourmaline (see fig. 4, p. 462). The occurrence of small amounts of pyroxenes in this type has already been noted.

Quartz forms large grains often aggregated into patches; lines of inclusions traverse the grains at right angles to the fluxion, when this is present.

Felspar occurs in three species. Most abundant is oligoclase-andesine in fresh well-formed crystals, often included in the quartz; this plagioclase is usually about 2 to 3 mm. long, but in certain rocks it builds porphyritic crystals with a maximum length of 1 cm. Extinction-angles on cleavage-flakes and the refractive index indicate that it has a composition of Ab_{70} An_{30}. Its sign is negative, but in rare cases a positive sign has been noted,

showing that occasionally it is as basic as andesine. Very fine albite and pericline twinning is seen. The second type of felspar is one which seems to merit the name of soda-microcline. This occurs in grains and crystals of late formation, which in most cases show a hazy lattice-twinning, best seen when the crystal is almost in the position of extinction. Extinctions on cleavage-

Fig. 4.—*Contaminated rocks.*



A & B, Arnage Type. Co.=cordierite; Pl.=oligoclase-andesine: Qz.=quartz; Bi.=biotite; Ga.=garnet; the solid black is iron-oxide; × 20 (see p. 463).

[The rock of B has been analysed: see Analysis VII, Table III, p. 464.]

C, Kinharrachie Type. Pl.=andesine: Qz.=quartz; Ho.=hornblende; × 30 (see p. 466).

D, Ardlethen Type. Pl.=oligoclase; Or.=orthoclase; Mic.=microcline; Qz.=quartz; Bi.=biotite; × 20 (see p. 472).

flakes are always low; the sign is negative. Its refractive index is distinctly higher than that of the orthoclase present, and has a mean value of 1·526. The optic axial angle is small, 2V being about 40°. This last observation, taken in conjunction with the other optical properties, indicates that this felspar is a microcline

containing a considerable percentage of the albite-molecule—a soda-microcline. Orthoclase is not abundant in this type: it occurs as grains of large size in certain specimens. Large grains of micropegmatite are noted in the rocks rich in alkali-felspar; these grains are either enclosed in the felspar, or lie at the borders of two felspar-grains.

Cordierite forms euhedral prisms, with well-developed trillings and magnificent pleochroic haloes around zircons. It is often enclosed by both felspar and quartz; but, from its characters, relation, and form, there can be no question that it is a true separation from the magma, and not xenocrystic from some pre-existing cordierite-bearing rock. In size it may reach 5 mm. or more in length; its haloes are often 0·25 mm. across. Occasionally it includes small biotite-flakes or green spinel-grains. It alters marginally and along cracks, either into yellowish serpentinous substances, or into micaceous products, which in later stages pass into individualized colourless mica-plates.

Biotite forms large plates, with a pleochroism from pale yellow-brown to deep red-black. These plates have often a tendency to finger out into the adjacent minerals, or to show a subskeletal form. They alter to green chlorite, exposing a delicate sagenitic web.

Garnet is of widespread occurrence, and builds pink subhedra often 1 cm. across; it encloses quartz-grains and biotite-flakes. Spinel forms clusters of deep-green grains enclosed in cordierite-patches. Sillimanite has been noted once, and then builds small prisms. Blue tourmaline is often seen; in one example it builds a micropegmatitic intergrowth with quartz between felspar-crystals. Iron-ore is not abundant, and forms black rounded grains usually associated with biotite. Zircon is of widespread occurrence; apatite is less common.

The relative proportion of the chief constituents is extraordinarily variable. Any of the four main components (quartz, cordierite, felspar, and biotite) may dominate, and single hand-specimens may show bands of very diverse ratios. Perhaps the main type, however, is one in which there are about equal amounts of quartz, cordierite, oligoclase-andesine, and biotite, with a few grains of soda-microcline and a spattering of garnet and spinel (see fig. 4). Two rocks of this type have been analysed, and these are included in Table III, Analyses VI & VII (p. 464). Occasionally, perhaps 80 per cent. of the rock may be formed of large crystals of cordierite, between which are grains of quartz, oligoclase-andesine, and a little biotite. Sometimes, on the other hand, cordierite may be absent, and the rock is composed of quartz, oligoclase-andesine, and biotite, of what is usually taken as a purely igneous aspect. Again, the relative amounts of the two main felspars varies; oligoclase-andesine is always present, while soda-microcline is often absent, but in some examples this latter felspar may be quite as abundant as the former. Quartz-rich varieties are common, and form granitic bands in the other variations. All these types occur

Table III.—Analyses of Arnage Contaminated Rocks.

	VI.	VII.	VIII.
SiO_2	62·39	47·88	69·84
TiO_2	0·99	1·49	0·60
Al_2O_3	17·33	26·35	13·16
Fe_2O_3	0·48	0·95	1·45
Cr_2O_3	nt. fd.	nt. fd.	...
V_2O_3	nt. fd.	nt. fd.	...
FeO	7·19	12·01	2·37
MnO	0·18	0·18	0·15
(CoNi)O	nt. fd.	nt. fd.	nt. fd.
BaO	0·03	0·01	0·11
CaO	2·10	2·91	2·13
MgO	2·81	2·87	1·06
K_2O	0·48	1·31	5·68
Na_2O	3·41	1·75	3·07
Li_2O	nt. fd.	trace	nt. fd.
H_2O at 105° C.	0·11	0·23	0·09
H_2O above 105° C.	1·47	1·32	0·06
P_2O_5	0·22	0·32	0·14
FeS_2	0·05	0·23	0·01
Fe_7S_8	0·58	0·16	...
CO_2	0·42	0·23	0·09
Totals	100·24	100·20	100·01

VI. Contaminated Rock of Arnage Type, quarry at the roadside, half a mile north-east of Mains of Drumwhindle, Arnage. Anal. E. G. Radley.

VII. Contaminated Rock of Arnage Type, Carding Hill, 700 yards south-south-east of Arnage House, Arnage. Anal. E. G. Radley.

VIII. Contaminated Rock of Ardlethen Type, quarry at the roadside, 340 yards south-south-east of Ardlethen. Anal. E. G. Radley. (See p. 467.)

in intimate association, but it may be said that the main type is a quartz-cordierite-felspar-biotite-rock (see fig. 4, p. 462).

The average diameter of the grains in these rocks is 1 to 2 mm. Usually there is a well-expressed fluxional structure, shown by the orientation of the biotite-flakes and the longer axes of cordierite and felspar-crystals. But rarely in this type is undulose extinction in the quartz observed, and the fluxion appears to be the result of flow of a pasty crystal-mush. A broader banding is often seen by the alignment of streaks of varying composition, and this is emphasized also by the filming-out of xenolithic relics. On a smaller scale is a patchiness observed in slice, evinced in cordierite-rich or biotite-rich streaks or patches of small size. Akin to these banded and patchy rocks are some which show imperfect kneading of the sediment-magma mixture. These rocks are of the usual type of cordierite-biotite-quartz-plagioclase-rock, but have certain bands rich in cordierite, often crowded with small spinels and biotite-plates; these bands appear to represent material largely of sedimentary origin, which has been but imperfectly incorporated in the contaminated magma. These streaks blend imperceptibly with the matrix, and appear to represent a very advanced stage of incorporation of xenoliths.

Certain of the bands in the Arnage Type are almost of granitic nature, being pale in colour and poor in cordierite.

(C) Hornblende-Biotite-Quartz-Plagioclase-Rock, or the Kinharrachie Type.

The second of the main types of contaminated rock is dioritic in composition, and is found between the Little Arnage kernel and the Ythan (see fig. 5, p. 468). Two series of exposures serve to explain the origin of this type: the first of these is supplied by the railway-cutting between Ellon and the Little Arnage kernel, supplemented by abundant rock-knobs in the ground due west of the railway towards Waulkmill; the second is provided by numerous outcrops in the woods between the Ellon-Methlick main road and the Ythan (see fig. 5). These two series of exposures are described in detail.

The railway-cutting in the rocks concerned begins at a point half a mile north of Ellon Station, and continues northwards for over a mile until the norite of the Little Arnage kernel is reached. A traverse from south to north along the cutting displays the characters and origin of this dioritic type very clearly. In the cutting due east of Mains of Auchterellon are found coarse hornblende-schists and subordinate biotite-gneisses of the Ellon Series; these schists are threaded with delicate strings of acid igneous material. The same association of country-rocks continues for three-quarters of a mile northwards along the cutting; but an increase in the amount of igneous material can be observed. At the road-bridge half a mile south of Little Arnage the blocks blasted from the cutting are piled up in a field on the west side of the railway, north of the road, and supply very clear evidence as to the nature of the rocks concerned. Country-rock still dominates, but a good deal of igneous veining is seen, and noteworthy is the presence of abundant garnets in both veins and host. Some hundred yards north of the bridge the rock definitely becomes mainly igneous, with hornfelsed xenolithic fragments of hornblende- and biotite-schists; northwards the amount of the igneous component increases, until the true norite of the Little Arnage kernel is reached. An exactly similar gradual passage from country-rock to contaminated rock can be seen in numerous traverses from the Ellon-Kinharrachie road, north-westwards to Waulkmill and Little Arnage. In the conspicuous knob between Hayhillock and Waulkmill the dioritic type is found in intimate association with rocks of the Arnage Type already described.

In hand-specimens the contaminated rock, largely of igneous origin, is usually coarse in grain and speckled with white felspars and black biotites and hornblendes; often the rock is homogeneous and of normal igneous aspect, but sometimes dark hornblendic or biotitic streaks, representing relic xenoliths, are visible. In many cases it would be an easy matter to conclude, from an inspection of hand-specimens alone and without field-knowledge, that the rocks under discussion should be regarded as true igneous rocks.

The mineral-content of this dioritic type is quartz, plagioclase, hornblende, biotite, pyroxene, and iron-oxide.

The quartz occurs mainly in lenticular areas made up of elongated grains, which usually show a slight undulose extinction. The felspar is a medium andesine, with a refractive index of 1·553, and forms stout crystals somewhat lenticular in outline. Fine albite and pericline twinning is developed. A few crystals of orthoclase have been noted. Biotite forms trains of small plates expressing the fluxion, or large individual plates; the pleochroism is from pale yellow to deep brown. Hornblende occurs in two types: the one forms collections of prisms, almost colourless in slice and exhibiting lamellar twinning, the other builds very large ophitic plates enclosing the felspar. This second variety is deeply coloured, and is pleochroic in yellow, green, and brown. Both varieties are usually found associated, but their time-relations are uncertain. Small areas of quartz-hornblende micropegmatite, akin to those resulting from reaction-processes, have been noted. Both monoclinic and rhombic pyroxenes occur. The monoclinic pyroxene is found only as rounded grains, associated with quartz and enclosed in large hornblende-plates; it is possibly of contact-origin (see p. 478). Hypersthene is rare; it occurs in subhedral grains showing vivid green and pink pleochroism, and is often associated with hornblende and biotite. Black iron-oxide forms grains in the mafic minerals, or scattered dirty particles (chiefly in the pale amphibole).

The relative amounts of hornblende and biotite vary, sometimes only a little hornblende being seen, at others only a little biotite; but usually about equal amounts of each occur.

These rocks show, especially in the biotite-rich types, a well-developed fluxional structure, made plain by the lenticular form assumed by the quartz and felspar and by the rude alignment of biotite-plates.

It is of importance to record that, in certain places at the northern end of the cutting described, the contaminated rock is richer in leucocratic minerals than usual, and approaches a hornblende-granite in appearance. The constituent minerals of this granitic type are dominant oligoclase-andesine, less common orthoclase and microcline, with biotite and hornblende, and the rock occurs as schlieren in the dioritic type.

The second series of exposures of contaminated rocks of Kinharrachie Type is found around West Kinharrachie, and can be easily studied in the wooded knolls lying between the Ellon-Methlick road and the River Ythan (see fig. 5, p. 468). There is here a very complete passage from hornblende-schists of the Ellon Series north-westwards into biotite- and hornblende-bearing contaminated rocks of dioritic aspect. Certain of the mixed rocks are richer in biotite, felspars, and quartz, and poorer in hornblende than the usual dioritic rock; they provide a hornblende-granitic type.

The biotite-gneisses and hornblende-schists of the Ellon Series

are seen near East Kinharrachie, where they are veined by a few acid strings composed of andesine and quartz. Farther north-west the number of acid strings increases, and the hornblende-schists appear in places to have mixed with the acid injections along the walls of the vein-passages, with the result that the threads hold considerable hornblende. Still farther north-westwards the veins broaden out and coalesce, and the rock assumes a xenolithic aspect. The rounded xenoliths lie in a matrix of coarse andesine, quartz, large hornblende-prisms, and biotite-plates. These early stages may be seen in many excellent exposures lying south-east of West Kinharrachie. At West Kinharrachie perhaps half the rock is of later igneous parentage, with 'ghosts' and small rounded xenoliths of hornblende-rock lying in a felspathic hornblendic matrix. In Craigouthorn Wood, north-west of West Kinharrachie, the hornblendic mixtures pass into biotite-plagioclase-quartz rocks resembling non-cordierite-bearing Arnage types. Still farther north-westwards towards the Mill the dominant rock is of Arnage Type, though here too are hornblendic lenticles. An instructive but much weathered section is seen in an old quarry at the roadside, 250 yards north of West Kinharrachie. Here the hornblendic acid mixture with its hornblendic xenoliths appears to have been engulfed as large blocks in the non-hornblendic, biotitic, Arnage-Type rock, which truncates the acid veins or matrix of the hornblendic type. This points to the conclusion that the acid veining supplies the loosening agent preparatory to the advance of the main body of biotitic contaminated rock.

In the details of their petrography the rock-types around Kinharrachie are like those already described from the railway-cutting (see fig. 4, p. 462). The hornblende occurs in the more magmatic types in large ophitic plates enclosing euhedral felspars. There is a well-marked fluxion in the more biotitic types. The contact-metamorphism suffered by the hornblende-schists is described in § VI, p. 478.

The rocks of the Kinharrachie area were described by J. S. Grant Wilson[1] as 'brecciated gneiss', and their outcrop was shown on the 1-inch geological map.

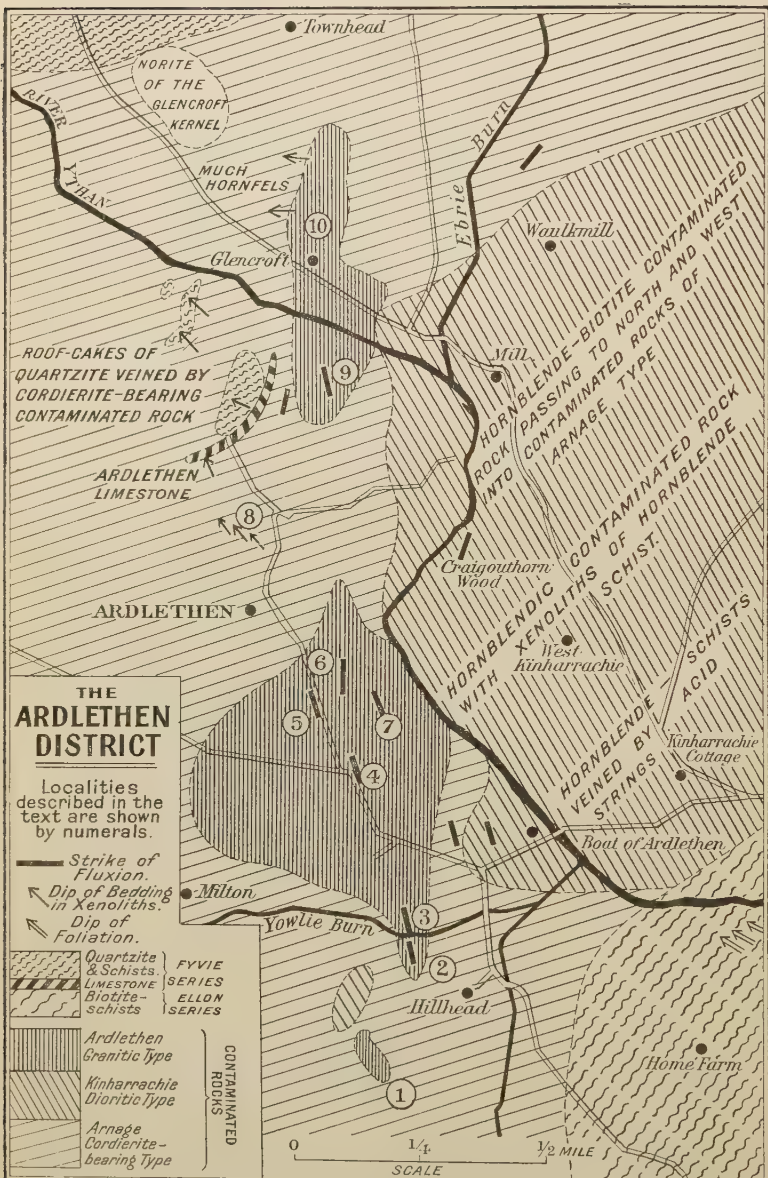
It has been demonstrated, therefore, that the result of contamination of the initial magma by the Ellon hornblende-schists is the production of rocks resembling quartz-diorites which, in places, pass into granitic types.

(D) Contaminated Rocks of the Ardlethen Area; the Ardlethen Type.

Now that the characters and origins of the contaminated rocks of Arnage and Kinharrachie Types have been discussed, the more intricate ground around Ardlethen (see fig. 5) may be considered. The area dealt with here comprises the Ardlethen estate south of

[1] 'Explanation of Sheet 87' Mem. Geol. Surv. Scot. 1886, p. 8.

Fig. 5.


Townhead
NORITE OF THE GLENCROFT KERNEL
RIVER YTHAN
Ebrie Burn
MUCH HORNFELS
Waulkmill
Glencroft
HORNBLENDE-BIOTITE CONTAMINATED ROCK PASSING TO NORTH AND WEST INTO CONTAMINATED ROCKS OF ARNAGE TYPE
Mill
ROOF-CAKES OF QUARTZITE VEINED BY CORDIERITE-BEARING CONTAMINATED ROCK
ARDLETHEN LIMESTONE
Craigouthorn Wood
HORNBLENDIC CONTAMINATED ROCK WITH XENOLITHS OF HORNBLENDE SCHIST.
ARDLETHEN
West Kinharrachie
HORNBLENDE SCHISTS VEINED BY ACID STRINGS
Kinharrachie Cottage
Boat of Ardlethen
THE ARDLETHEN DISTRICT
Localities described in the text are shown by numerals.
Strike of Fluxion.
Dip of Bedding in Xenoliths.
Dip of Foliation.
Milton
Yowlie Burn
Hillhead
Home Farm
Quartzite & Schists. LIMESTONE FYVIE SERIES
Biotite-schists ELLON SERIES
Ardlethen Granitic Type
Kinharrachie Dioritic Type
Arnage Cordierite-bearing Type
CONTAMINATED ROCKS
0 1/4 1/2 MILE
SCALE

the Ythan, and the ground around Glencroft north of that river. A large part of this ground is well exposed; especially is this the case along the Ythan Valley proper.

In the Ardlethen district we encounter again the Arnage Type (cordierite-biotite-quartz-oligoclase-rock) and the Kinharrachie Type (hornblende-biotite-andesine-quartz-rock); but the most important feature is the development of an acid facies of the contaminated rocks—the Ardlethen Type. This acid phase appears to pass, near Glencroft, into a rock of so normal a granitic nature that at first it was mapped as a granite of an ancestry in which contamination had played no part. In addition to these points of petrogenetic value, there are at Ardlethen certain structural features of interest. The development of the Arnage and Kinharrachie Types will be described first, and then the granitic end-products of Ardlethen Type.

Contaminated rocks of Arnage Type are found along the southern margin of the Mass from Hillhead of Ardlethen to the Cat Craigs north of Ythsie; they occur also, among other places, in the wood half a mile north of Ardlethen, near Ardlethen itself, and a third of a mile north of Glencroft. In all cases they hold abundant xenoliths, either of hornfelsed biotite-schist of the Ellon Series, or of hornfelsed andalusite-schist of the Fyvie Series. In slices, rocks of this type are like those already described from Arnage, and are composed of quartz, oligoclase, biotite, and cordierite, with often abundant green spinel and pink garnet. Certain of the rocks of this class contain much soda-microcline and orthoclase, and provide excellent transitions towards the Ardlethen Type presently described. Others lack cordierite, and afford a second transition to the acid end-product. As will be noted later (see p. 470), the cordierite-bearing type appears to pass into the granitic Ardlethen Type.

Some interesting phenomena, seen in the wood nearly half a mile north of Ardlethen, may here be noted. When this wood is viewed from the north, say from a point near Glencroft, it is observed that there is a conspicuous hump in the general even sweep of trees. When investigated more closely, this hump is seen to be due to a cake of quartzite floating, as it were, on the contaminated magmatic rock around it. This quartzite is part of the Fyvie Series, and forms a cake, 400 yards long, in which the bedding dips steeply westwards. With the quartzite is associated a narrow belt of limestone, seen at Ardlethen Quarry, and in the wood 660 yards north by west and 900 yards north of Ardlethen (see fig. 5). There can be no doubt that these represent patches of the sedimentary roof preserved upon the contaminated belt. It is to be noted that this quartzite cake is veined by cordierite-bearing contaminated rocks, which carry xenoliths of blue argillaceous hornfels. The inference can be drawn therefrom that the quartzite cake owes its preservation to its greater resistance to the corrosive action of the magma. What are best considered as further examples of these roof-phenomena are seen 1000 yards and 1200 yards

respectively west-north-west of Glencroft. The dips of the bedding in all these roof-cakes are the same. Not much different are the dips of the bedding in the smaller xenoliths in the ground near Ardlethen and out towards Ythsie. These are roof-phenomena.

The diorite or hornblende-biotite-felspar-quartz-rock of Kinharrachie Type is simply the southern continuation of that type from the north side of the Ythan (fig. 5). Such types occur in Boat Wood, 200 yards west of Boat of Ardlethen, in the wood 400 yards west of Hillhead of Ardlethen, and in the roadside quarry 340 yards south-south-east of Ardlethen. West of Boat Wood this type is of subordinate importance, and occurs only as patches in rocks of Arnage or Ardlethen types. In slice, rocks of the diorite type show coarse associations of quartz, oligoclase-andesine and andesine, large plates of biotite, and ophitic hornblende-plates.

Occasionally, as in the wood 1000 yards north of Ardlethen, the contaminated rocks are hypersthene-bearing. They are composed of hypersthene, hornblende, biotite, quartz, and an intermediate plagioclase; they are to be compared with the Gabbro Type discussed on p. 458.

The Ardlethen Type occurs in three areas north and south of Ardlethen (fig. 5, p. 468). The structural relations of this type to the rocks just described will be best discussed by considering certain of the localities at which they are well seen. In fig. 5 these localities are shown by numerals: fluxion in these and the adjacent rocks is indicated also in the figure.

Locality 1.—400 yards south-west of Hillhead of Ardlethen.—This is a poor exposure, but sufficient is seen to provide an introduction to the problem. Rock of Ardlethen Type is here intimately associated with cordierite-biotite-oligoclase-quartz-rock of Arnage Type; the whole is streaky, fluxional, and xenolithic, variable in grain and in distribution of biotite, which occurs often in felts in the more acid rocks. A variation from Ardlethen Type to Arnage Type is often seen in the same block. The inference can be drawn that here the granitic end-product occurs as lenticles and streaks in the dominant cordierite-bearing Arnage Type, and, like it, must be considered to be of contaminated origin.

Locality 2.—In the wood, south of the Yowlie Burn, 300 yards north-west of Hillhead of Ardlethen.—At a point 100 yards south of the Yowlie Burn are seen magnificent crags of garnetiferous cordierite-contaminated rocks of Arnage Type, with abundant blue hornfels-xenoliths; a good flow-structure strikes north 15° west. Northwards from this locality we encounter a perfect and gradual passage from these Arnage Type rocks with abundant xenoliths into more felspathic types with fewer xenoliths, and from these again into a gneissose granitic Ardlethen Type, with no xenoliths beyond a few streaks of aggregated biotite of the thickness of cardboard. The whole

transition occupies a width of about 10 yards perpendicular to the direction of flow. It is important to note that the fluxion becomes more intense with the development of granitic character, and maintains a rigid direction of north 15° west over the whole exposure.

Locality 3.—Quarry, north of the Yowlie Burn, 350 yards north-west of Hillhead of Ardlethen.—A freshly quarried face here gives another transition from a western outcrop of xenolithic Arnage Type to a mass mainly of acid Ardlethen Type, with streaks and bands of dark biotite-rich, felspar-poor rock; the acid type passes eastwards into a biotite-rich contaminated rock, with flattened lenticles of xenoliths. The strike of the fluxion and streaking is north 15° west in both Arnage and Ardlethen Types. This constancy of the strike of the fluxion, observed at both Locality 2 and Locality 3, shows that the two rock-types belong to the same period of intrusion, and that the granitic product cannot be interpreted as a later intrusion—a conclusion confirmed by the complete absence of intrusive junctions and by the detailed petrography of the product (see p. 472).

Locality 4.—Old quarry, at the roadfork, 640 yards south-south-east of Ardlethen.—This quarry is much overgrown, but shows the acidic Ardlethen Type with fluxion running north 20° west. The rock holds a few ghosts of xenoliths.

Locality 5.—Quarry, at the roadside, 340 yards south-south-east of Ardlethen.—This small quarry shows many varieties of contaminated rock, the main variety being a pink, streaky, acidic Ardlethen Type, with less common hornblendic and biotite-rich Arnage Types. All these varieties occur in bands striking north 15° west, and showing a fluxion in the same direction. An acid rock from this locality has been analysed (see Analysis VIII, Table III, p. 464).

Locality 6.—Wood, 350 yards south-east of Ardlethen.—Here occurs a massive homogeneous acid rock, with no visible xenoliths, and showing flow-structure which strikes north 10° east.

Locality 7.—Craigiehill Wood, 700 yards south-east of Ardlethen.—Many bold crags in this wood show a close association of contaminated rocks of Arnage and Ardlethen Types, the former containing garnets and blue hornfels-xenoliths. The strike of the fluxion varies from north 20° west to north 5° west, and is seen in both types of rock.

Locality 8.—250 yards north of Ardlethen.—Garnetiferous and cordierite-bearing acidified products are here seen lit-par-lit injected into, and mixed by absorption with, garnetiferous blue hornfelses. The contaminated rocks vary from a cordierite-bearing granitic Ardlethen Type, back to a cordierite and biotite-rich type of normal Arnage facies.

Locality 9.—Wood, south of the Ythan, 450 yards south of Glencroft.—Here crags of coarse fluxional granitic end-product, with no visible xenoliths, occur. The width of the outcrop in an east-and-west direction exceeds 200 yards, and on both sides are passages to a cordierite-biotite mixture of Arnage Type, with multitudes of blue hornfels-xenoliths. The fluxion in the Ardlethen Type strikes north 5° west.

Locality 10.—Glencroft Quarry.—The quarry itself is in solid granite. Westwards and south-eastwards the granite is mixed with contaminated rocks of Arnage Type bearing blue hornfels-xenoliths. On the furze-clad ground north of the quarry the granite is often xenolithic, and passes northwards into the true Ardlethen Type, and this into the Arnage Type still farther north.

These localities show, therefore, gradual transitions from a cordierite-bearing Arnage Type with xenoliths to a granitic Ardlethen Type without xenoliths, and in one place (Glencroft Quarry) the Ardlethen Type appears to pass into a granite of normal character and aspect. A common fluxion is seen in both the Arnage and the Ardlethen Types, and the latter occurs as schlieren, bands, or big lenticles in the former. It will be remembered, too, that in the main development of the Arnage Type, north of the Ythan around Arnage, there are granitic bands and streaks of small size.

Petrography of the Ardlethen Type.—In hand-specimens the granitic rocks of Ardlethen Type always show a pronounced fluxional structure, by which the large felspars (up to 1 cm. long) and quartz become lenticular, and are wrapped about by biotite films so that the rock simulates an augen-gneiss. In colour, the rocks are pale (the felspars being whitish or pinkish), and streaked with dark biotite-films.

In slice, the components of the Ardlethen Type are seen to be quartz, various felspars, and biotite, with less common garnet, cordierite, and spinel.

The quartz forms aggregates of grains often showing undulose extinction; the alignment of the larger axes of the aggregates helps to provide the fluxional structure. The felspars are of various kinds: chief is oligoclase in large crystals, often showing pressure-effects, and lenticular in outline. The plagioclase is rarely as basic as andesine. Less important than the plagioclase, though still abundant, are orthoclase and microcline, which also occur in large plates similarly lenticular. The orthoclase is normal, and rarely shows microperthitic structure. The microcline has a well-developed cross-hatching and a large optic axial angle: its albite-molecule must be subordinate, in contrast to its importance in the soda-microcline of certain rocks of the Arnage Type already described. Grains, often of large size, of micropegmatite are common, and often almost completely surround alkali-felspar crystals; grains of myrmekite are rare. Biotite, pleochroic in pale yellow to deep brown-black, occurs either in

laths or stouter plates wrapping round the felspars. In some examples the biotite is abundant, forming a felt pricked through by small felspars and quartzes. There are, too, streaks richer in biotite than the normal rock, which probably represent relics of xenoliths of biotite-schist.

The minerals just described constitute the usual Ardlethen Type (see fig. 4, p. 462); there remain, however, certain minerals of some importance to be noted. Garnet in rounded pinkish grains is widespread, though not abundant. Spinel occurs in clusters and streaks associated with cordierite; these undoubtedly represent far-gone xenoliths of argillaceous composition. The occurrence of these minerals characteristic of the definitely contaminated rocks adds strength to the view that the Ardlethen granitic type is of contaminated origin.

The rock seen in Glencroft Quarry is a granite with only a poorly-developed fluxion. It is composed of biotite, the felspars of the Ardlethen Type, and quartz. Here, too, may be noted a tendency for the biotites to be clustered into rude streaks.

An average rock of Ardlethen Type has been analysed by Mr. E. G. Radley; this analysis is set forth in Table III, p. 464.

VI. The Xenoliths and Hornfelses.

The two series of Highland Schists taking part in the contamination of the initial magma provide recognizable xenoliths in the contaminated rocks; these xenoliths give examples of exceptionally beautiful hornfelses, and, moreover, they play, or their like have played, a very important part in the contamination-process. No definite aureole has been found around the Arnage Mass, and such is not to be expected, considering the gradual passage from country-rock to contaminated rock that is everywhere encountered.

The broad distributions of the xenoliths belonging to the two main rock-series—the Fyvie and the Ellon Series—are shown in fig. 2 (p. 452). It has been pointed out, also, in the description of the contaminated rocks, that the Arnage and Kinharrachie Types carry xenoliths of argillaceous schists of the Ellon and Fyvie Series and hornblende-schists of the Ellon Series respectively. The reader may thus form some notion of the distribution of the different types of xenoliths. With regard to the number of xenoliths, it may be stated that they must be reckoned in hundreds of thousands in contaminated rocks of Kinharrachie and Arnage Type; but they are rare in the Ardlethen granitic type, and only one has been noted in the norite of the kernels.

Four types of xenoliths are met with, corresponding to the original rock-types of (1) felspathic quartzite of the Fyvie Series, (2) andalusite-schist of the Fyvie Series, (3) biotite-schist of the Ellon Series, and (4) hornblende-schist of the Ellon Series.

Some of the multitudinous details noted of the mode of occurrence of the xenoliths may be given. The strike and dip of the bedding of the larger xenoliths agree with those of the adjacent

country-rock (see figs. 2 & 5, pp. 452, 468); examples have already been described from Towie Wood (p. 459), Ardlethen (p. 469), and elsewhere. The process of lit-par-lit injection does not markedly disturb the lie of the xenoliths. In the case of the smaller xenoliths, no definite orientation is to be seen, except that their longer axes agree in direction with the fluxion when this is at all well expressed.

In size, the xenoliths vary from yards to fractions of an inch across, but an average size for slaty xenoliths is about 3 inches long by 1 inch wide, and about half an inch thick.

The slaty xenoliths, and those of the hornblende-schist produced by the coalescence of the Kinharrachie veins (see p. 467), are rounded in form; but quite different are those of quartzite of the Fyvie Series, which are angular and have sharp, straight edges. It is instructive, too, to compare the sizes of the argillaceous and quartzose xenoliths occurring in the same rock-exposures of the Arnage Type:—

Measurements in Inches.

(1) Gallowhill.—Quartzose xenoliths: 12×3; 6×2; 7×3; 16×6; 24×4.
Argillaceous xenoliths: 2×1; 4×2; $2\times\frac{1}{2}$; $2\times\frac{3}{4}$.

(2) South of Waulkmill of Savoch.—Quartzose xenoliths: 7×4; 3×3; 9×1; $2\frac{1}{2}\times\frac{3}{4}$; 10×6.
Argillaceous xenoliths: faint 'ghosts' only seen.

(3) Towie Wood.—Quartzose xenoliths: $23\times6\frac{1}{2}$; 24×6; 7×4; $3\times1\frac{1}{2}$; 6×3.
Argillaceous xenoliths: 11×3; $12\times1\frac{1}{2}$; 4×1; and many smaller.

The conclusion appears to be warranted that argillaceous sediments are more readily reacted upon by the initial magma than is quartzite. The same result is seen in the Ardlethen roof-cake (see p. 469), which is composed of quartzite, but floats upon and is veined by contaminated rock carrying argillaceous xenoliths. We see too, perhaps, an expression of the same phenomenon in the nesting of the contaminated rock by quartz, which seems to have been rejected and segregated in the contamination-process. It may be concluded, then, that the most important contaminator for the Arnage Type of product is sediment of argillaceous nature.

The only xenolith observed in the norite-sheet may here be noted; it consists of quartzite, and stands up wall-like in the norite in the railway-cutting south of Burngrains. The norite is norite and the quartzite quartzite up to the very junction-planes.

Petrography.

The hornfelses of the Arnage district are of such beauty that it is considered advisable to make them the subject of another communication. Enough will be said here, however, to enable the reader to form an idea of their nature and composition, since they play an important part in the contamination-process. The

xenoliths and hornfelses are now described under the headings of their original rock-types.

Limestone.—Limestone forms part of the Ardlethen roof-cake, but has not been recognized as xenolithic in the contaminated rocks. At Ardlethen the hornfelsed rock consists mainly of large grains of calcite, with a few small grains of pale monoclinic pyroxene, tremolite-prisms, and scarce plates of pale mica.

Felspathic quartzite.—The hornfelsed quartzites of the Fyvie Series are mainly coarse-grained massive rocks breaking with a splintery fracture. They are composed of quartz in large sutured grains often elongated in form, together with subordinate smaller acid or medium plagioclase-grains similarly elongated. There is occasionally a very pronounced parallel structure, as if recrystallization had taken place under pressure. Sometimes the felspar-plates are speckled with quartz-pellets, at others the small felspar-grains are disposed around the edge of the large quartz-grains. A few grains of zoisite have been noted in a similar position. Biotite is of common occurrence, but usually in no great amount. Garnet in rude pink grains is often noted. In some rocks of this group the 'cement' between the quartz-grains is formed wholly of cordierite. Certain of the quartzose hornfelses of the Ardlethen district are extremely fine-grained, and consist of an assemblage of minute grains of quartz, plagioclase, and biotite.

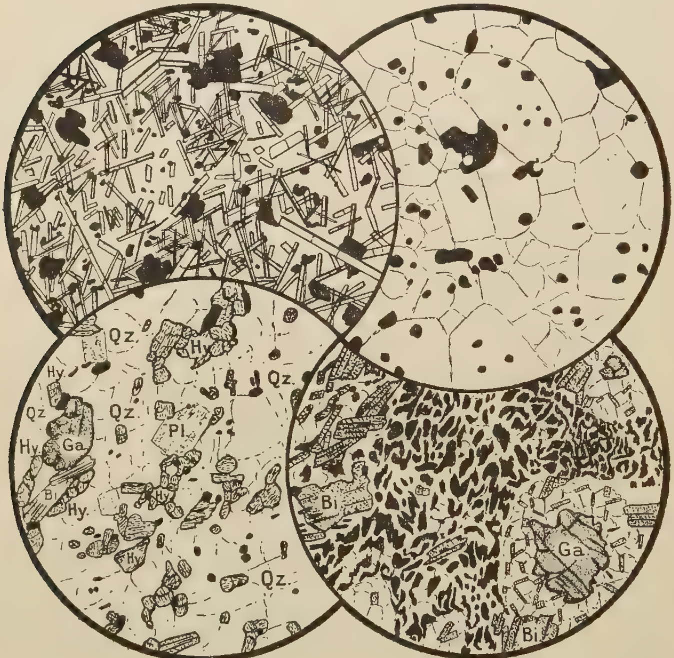
Hornfelsed andalusite-schists; the slaty hornfelses. -Certain of the argillaceous hornfelses from the country-rock area of fig. 2 (p. 452) appear to represent the andalusite-schist of the Fyvie Series, altered to a less degree than are xenoliths of this rock found within the contaminated rocks. In this type of hornfels the division between andalusite-porphyroblasts and ground-mass of the original rock persists as a separation between patches of cordierite and a more finely-grained base of quartz, cordierite, biotite, and felspar. In the hand-specimen these rocks are blotched with bluish patches of cordierite; in slice, large areas of cordierite, often 1 cm. across, are set in a fine recrystallized base of biotite-laths, pleochroic from pale yellow to rich red, quartz-grains, small cordierite-grains, and acid plagioclase-pellets. Often the cordierite has been replaced by muscovite. But rarely does andalusite persist in these hornfelses, and then it forms large limpid crystals, with an intense patchy pleochroism from pink to colourless; this andalusite is quite free from inclusions, and in this respect is in marked contrast to the inclusion-filled andalusite of the original rock. A similar type of andalusite has been described in a contact-metamorphosed andalusite-schist from Cloichdubh Hill, Strathbogie.[1]

[1] H. H. Read, 'Summary of Progress for 1918' Mem. Geol. Surv. 1919, p. 31.

Within the area of xenolith-bearing contaminated rocks, the blotched hornfels is replaced by a dense, compact, blue hornfels which forms the dominant argillaceous xenolith. This rock is usually quite massive, and but rarely shows a composition-banding.

Fig. 6.—*Xenoliths.*

A *B*



C *D*

A=Prisms of sillimanite and clots of spinel in a base of cordierite, with a few grains of plagioclase; ×30. The original rock was andalusite-schist of the Fyvie Series. (See p. 477.)

B=Grains of spinel in cordierite; ×30. The original rock was the same as in the case of A. An analysis of this rock is given in Table IV, p. 477.

C=Garnet (Ga.), hypersthene (Hy.), biotite (Bi.), quartz (Qz.), and plagioclase (Pl.); ×30. The original rock was probably a grit of the Fyvie Series. (See p. 477.)

D=Garnet (Ga.), biotite (Bi.), spinel (solid black), and cordierite (colourless); ×20. The original rock was a biotite-schist of the Ellon Series. (See p. 478.)

Certain of these hornfelses are deep blue in colour, and then break with a glassy fracture; they are almost pure cordierite.

The minerals of these hornfelses are cordierite, spinel, sillimanite and garnet, with plagioclase, hypersthene, quartz, biotite, and

alkali-felspar in less amount. The cordierite in some specimens forms perhaps 97 per cent. of the rock; it builds patches or grains, and is repeatedly twinned, often with the production of fantastic chequered patterns; it shows good haloes around zircons; its decomposition-products are pale micas. Spinel occurs as green angular grains in swarms in the cordierite, or associated with sillimanite; these grains occasionally reach 0·5 mm. in diameter. Sillimanite is common; it forms long needles, sometimes so abundant that the slice shows a dense matted felt interrupted by cordierite-grains (see fig. 6, p. 476); another mode of occurrence is as large aggregate prisms made up of parallel oriented smaller prisms, the large aggregate often measuring 0·5 cm. across. Garnet forms pink spongy aggregates enclosing quartz and biotite. Acid plagioclase, both oligoclase and acid andesine, is not abundant, and occurs as grains often speckled by other components. Some alkali-felspar is noted in certain examples. Quartz is common in some of the banded types. Biotite is never abundant, and is the usual hornfels-biotite, pleochroic from pale yellow to deep rich red. A noteworthy constituent of some examples of this type of hornfelses is hypersthene, which forms rounded, vividly pleochroic grains of small size, associated with quartz, biotite, and plagioclase.

The dominant hornfels of this class is one composed mainly of cordierite, with quite subordinate amounts of spinel and sillimanite and a few grains of felspar and quartz. The rock, the analysis

TABLE IV.—ANALYSIS OF CORDIERITE-HORNFELS.

	IX.
SiO_2	45·85
TiO_2	1·15
Al_2O_3	20·50
Fe_2O_3	11·91
Cr_2O_3	...
V_2O_3	...
FeO	11·32
MnO	0·26
(CoNi)O	nt. fd.
BaO	nt. fd.
CaO	1·27
MgO	4·18
K_2O	0·72
Na_2O	1·27
Li_2O	nt. fd.
H_2O at 105° C.	0·07
H_2O above 105° C.	1·48
P_2O_5	0·04
FeS_2	0·07
Fe_7S_8	...
CO_2	nt. fd.
Total	100·09

IX. Cordierite-spinel-hornfels, Gallowhill Brae, Arnage.
Anal. E. G. Radley (see p. 478).

of which is set forth on p. 477, shows in slice perhaps 97 per cent. of cordierite, some spinel, a few plates of biotite, and scarce plagioclase-grains—it is almost a cordierite-rock. The analysis reveals an unexpectedly large amount of iron-oxides. It seems that, in the cordierite of this rock, iron-oxides replace much of the alumina and magnesia of normal cordierite. Other hornfelses of this type are rich in sillimanite.

A second type of hornfelses of this class is richer in quartz, and bears biotite and garnet: this type tends to be banded. A variant is the hypersthene-hornfels which, in addition to the minerals just noted, has certain bands rich in grains of hypersthene.

Biotite-schist.—Hornfelsed biotite-schists of the Ellon Series are coarsely-banded rocks made up of varying associations of cordierite, biotite, quartz, plagioclase, spinel, garnet, and sillimanite. These ingredients are arranged in rude bands dominated by certain minerals. The two chief types of bands are composed of cordierite, spinel, and sillimanite, and of garnet, biotite, quartz, and plagioclase respectively. Cordierite forms irregular grains collected into lenticles or bands; pleochroic haloes are magnificently developed, and there are some sector-trillings; occasionally, intergrowths with quartz have been noted. Spinel is so extremely abundant that green bands appear in the slice; it forms irregular grains of a deep-green colour and clustered in cordierite bands; it is not found near garnet (see fig. 6, p. 476). Sillimanite is not abundant, and occurs as colourless prisms or needles in cordierite- and spinel-layers. Garnet builds large pink grains, sometimes spongy and with biotite-plates arranged in ocellar fashion around them. The biotite is pleochroic from pale yellow to deep red, and occurs as small plates in the cordierite-spinel bands and large plates in the biotite-rich bands. Quartz-grains, acid plagioclase-grains, and magnetite complete the rock.

Hornblende-schist.—The hornblende-schist of the Ellon Series occurring in the contaminated rocks is usually richer in biotite than the normal hornblende-schist. There is a more or less marked tendency for both hornblende and biotite to form very large plates sieved through by quartz and plagioclase, or to form, as it were, a cement to these minerals. In certain xenoliths taken out of the contaminated rocks of Craigouthorn Wood, north of West Kinharrachie, the rock is composed of masses of pale poikiloblastic hornblendes enclosing small rounded plagioclases and quartzes.

Another result of contact-metamorphism of the hornblende-schists is the formation of pyroxene. The normal hornblende-felspar rock is interrupted by small rounded patches consisting of an intergrowth of hypersthene with plagioclase and magnetite, the last often forming central threads to the ramifying hypersthenes. In other cases the newly-formed hypersthene builds stout crystals replacing portions of the hornblende.

VII. The Contamination Process.

For the purposes of this paper I shall regard the Arnage norite as the initial magma of the Arnage district, although I believe it likely that this view will be found to require some modification as research in contaminated rocks progresses.

We may consider the results which followed from the intrusion of a sheet-like mass in the Arnage ground. At the top of the sheet was formed a xenolithic zone some hundreds of feet thick (see section, fig. 2, p. 452); this zone we now see as the contaminated zone lying above the norite sheet.

The matrix of the xenolithic zone is what has here been described as contaminated rock. Contaminated rocks derived from gabbros necessarily are extremely variable; but there are certain striking regularities about their compositions which are of great importance. In Table V, p. 480, are enumerated the probable initial magmas and their contaminated derivatives for the Arnage, Insch,[1] and Huntly[2] Masses in the North-East of Scotland, for Le Pallet[3] in France, and for Minnesota[4]: that is, for the five described cases of contaminated gabbros. There are available at present three analyses of contaminated rocks of Arnage, one of Insch and two of Huntly; Prof. Lacroix gives six analyses of contaminated gabbros from Le Pallet which are averaged in Analysis D_1, Table V, while the average of two analyses of his initial magma is represented by Analysis D; Prof. Winchell supplies one analysis of the Snowbank Lake contaminated gabbro, and his initial gabbro is taken to be the olivine-gabbro also analysed by him. There are available, therefore, thirteen analyses of contaminated gabbros.

The chemical differences between the initial magmas and the contaminated derivatives may be deduced from Table V. The chief oxides are dealt with here. Silica is mainly increased in the contaminated magmas; alumina (with one exception) increases, and sometimes markedly; there is a general rise in ferrous oxide, but of no great magnitude in any case; lime is always much less; magnesia, with one exception, is much less too; potash in the majority of cases is increased; soda is rather indefinite, but seems upon the whole to increase; soda is always greater than potash in the initial magmas, but the disparity is either less marked, or potash is in excess of soda in the contaminated magmas.

Summarizing these observations, we find that in contamination the gabbro magmas become richer in alumina and potash, and poorer in lime and magnesia; iron-oxides and soda appear to play no constant part.

[1] H. H. Read, 'Geology of the Country round Banff, Huntly, & Turriff' (Explanation of Sheets 86 & 96) Mem. Geol. Surv. Scot. 1923, Chap. VII.

[2] *Id. ibid.*; and W. R. Watt, 'Geology of the Country around Huntly (Aberdeenshire)' Q. J. G. S. vol. lxx (1914) p. 266.

[3] A. Lacroix, 'Le Gabbro du Pallet & ses Modifications' Bull. Carte Géol. France, vol. x (1898–99) p. 341.

[4] A. N. Winchell, 'Mineralogical & Petrographic Study of the Gabbroid Rocks of Minnesota, &c.' Amer. Geologist, vol. xxvi (1900) p. 151.

TABLE V.—INITIAL MAGMAS AND THEIR CONTAMINATED DERIVATIVES.

	ARNAGE.				INSCH.		HUNTLY.			LE PALLET.		MINNESOTA.	
	Assumed Initial Magma.	Contaminated Rocks.			Initial Magma.	Contaminated Rock.	Initial Magma.	Contaminated Rocks.		Initial Magma.	Contaminated Rock.	Initial Magma.	Contaminated Rock.
	A.	A_1.	A_2.	A_3.	B.	B_1.	C.	C_1.	C_2.	D.	D_1.	E.	E_1.
SiO_2	52·04	62·39	47·88	69·84	49·30	56·18	49·18	59·15	48·00	49·53	53·3	47·70	52·84
TiO_2	0·66	0·99	1·49	0·60	3·19	1·54	1·24	1·14	0·99	...	...	1·80	trace
Al_2O_3	16·31	17·33	26·35	13·16	14·03	19·17	16·00	14·09	24·74	21·00	25·4	19·04	23·62
Fe_2O_3	0·06	0·48	0·95	1·45	0·09	0·47	0·02	1·04	0·18			0·87	0·65
Cr_2O_3	0·05	nt. fd.	nt. fd.	...	nt. fd.	nt. fd.	0·03	nt. fd.	0·21	10·24	11·0	...	...
V_2O_3	0·01	nt. fd.	nt. fd.	...	nt. fd.	nt. fd.	nt. fd.	nt. fd.	trace			...	...
FeO	7·98	7·19	12·01	2·37	9·61	9·84	8·02	7·73	11·03			8·84	10·00
MnO	0·14	0·18	0·18	0·15	0·31	0·15	0·20	0·24	0·24	...	...	trace	0·43
(CoNi)O	nt. fd.	nt. fd.	nt. fd.	nt. fd.	nt. fd.	nt. fd.	nt. fd.	nt. fd.	nt. fd.	...	...	...	...
BaO	trace	0·03	0·01	0·11	nt. fd.	0·09	trace	0·06	0·06	...	...	...	...
CaO	7·24	2·10	2·91	2·13	12·31	2·16	12·54	3·43	0·99	10·08	2·0	8·96	3·92
MgO	11·70	2·81	2·87	1·06	6·82	2·97	9·47	7·11	9·94	6·58	4·0	8·65	3·16
K_2O	0·89	0·48	1·31	5·68	0·30	2·61	0·26	2·44	1·47	0·24	0·7	0·53	0·67
Na_2O	1·82	3·41	1·75	3·07	2·66	1·71	2·04	1·10	0·84	2·44	3·3	2·53	2·64
Li_2O	trace	nt. fd.	trace	nt. fd.	trace	trace	trace	trace	trace	...	...	...	...
H_2O at 105° C.	0·06	0·11	0·23	0·09	0·11	0·28	0·07	0·44	0·06	0·40	0·7	1·38	1·87
H_2O above 105° C.	0·51	1·47	1·32	0·06	0·76	1·85	0·41	0·97	0·97				
P_2O_5	0·08	0·22	0·32	0·14	0·05	0·09	0·10	0·13	0·06	...	...	...	...
FeS_2	0·02	0·05	0·23	0·01	0·08	0·28	0·02	0·05	0·59	...	...	...	...
Fe_7S_8	0·51	0·58	0·16	...	nt. fd.	0·49	0·37	0·90	...	...	...	...	...
CO_2	0·46	0·42	0·23	0·09	0·42	0·15	0·33	0·03	...	...	...	...	...
Totals	100·54	100·24	100·20	100·01	100·04	100·03	100·30	100·05	100·37	100·51	100·4	100·30	99·80

Arnage.

A. Norite of the Arnage Mass, repeated from p. 457.

A_1. Contaminated rock (see p. 463) : Quarry at the roadside, half a mile north-east of Mains of Drumwhindle, Arnage. Analyst, E. G. Radley. 'Summary of Progress for 1921' Mem. Geol. Surv. 1922, p. 107.

A_2. Contaminated rock (see p. 463) : Carding Hill, 700 yards south-south-east of Arnage House, Arnage. Analyst, E. G. Radley, *loc. cit.*

A_3. Contaminated rock of Ardlethen Type (see p. 472) : Quarry at the roadside, 340 yards south-south-east of Ardlethen. Analyst, E. G. Radley.

Insch.

B. Hypersthene-gabbro of the Insch Mass. Analyst, E. G. Radley, *loc. cit.* Mem. p124. II

B_1. Contaminated rock, Insch Mass, 400 yards south by east of Easter Saphock, Old Meldrum. Analyst, E. G. Radley, *loc. cit.*

Huntly.

C. Norite of Huntly Mass. Analyst, E. G. Radley, *loc cit.*

C_1. Contaminated rock, right bank of the River Deveron, 359 yards east of Castle Bridge, Huntly. Analyst, E. G. Radley.

C_2. Contaminated rock, Cuternach, Huntly. Analyst, E. G. Radley; quoted from W. R. Watt, Q. J. G. S. vol. lxx (1914) p. 289.

Le Pallet.

D. Gabbro, Le Pallet (Loire Inférieure), France. Analysts, Lacroix & Pisani. Average of two analyses. A. Lacroix, Bull. Carte Géol. France, vol. x (1898–99) p. 363, Analysis j.

D_1. Contaminated rocks, Le Pallet. Analysts, Lacroix & Pisani. Average of six analyses. A. Lacroix, *ibid.* p. 363, Analysis i.

Minnesota.

E. Olivine-gabbro, Birch Lake (Minnesota). Analyst, A. N. Winchell, Amer. Geol. vol. xxvi (1900) p. 181.

E_1. Contaminated gabbro (cordierite-norite), Snowbank Lake (Minnesota). Analyst, A. N. Winchell, *ibid.* p. 303.

It is now pertinent to enquire into the source of the oxides gained, and the destination of the oxides lost, by the initial magmas. The answer to both these queries can only be the xenoliths. In Table VI, Analyses X–XIII (p. 482) we have a fine series of analyses which add considerable strength to this view. These four analyses, from the Huntly Mass, are of the initial sediment, a xenolith, the contaminated rock adjacent to this xenolith, and the initial magma. It will be seen that, compared with the initial magma, the contaminated rock is poorer in lime and magnesia, while, compared with the initial sediment, the xenolith is richer in these two oxides. In other words, the sums of lime, magnesia, and potash of the two initial rocks approximately equal the sums of the same oxides of the two resultant rocks.[1] It must be admitted that the other oxides show no very intelligible variation, but this series of analyses demonstrates that certain of the oxides lost by the magma are found in the xenoliths.

As yet, I can advance no such striking chemical proof from the Arnage Mass. The analysis of the Arnage cordierite-hornfels (Table VI, Analysis XIV) gives surprisingly low alumina and

[1] For a fuller discussion of this series of analyses, see H. H. Read, 'Geology of the Country round Banff, Huntly, & Turriff' (Explanation of Sheets 86 & 96) Mem. Geol. Surv. Scot. 1923, Chap. vii.

magnesia and high iron-oxides for this type of rock. However, the mineralogical character of the xenoliths in the Arnage type of contaminated rock does not invalidate the opinion that here also there has been a gain of magnesia by the xenoliths. From the Huntly and Insch Masses I have obtained xenoliths, of undoubted sedimentary origin, composed largely of monoclinic pyroxene.[1]

Table VI.—Analyses of Xenoliths, etc.

	X.	XI.	XII.	XIII.	XIV.	XV.	XVI.
SiO_2	53·98	59·98	59·15	49·18	45·85	54·00	60·50
TiO_2	1·15	0·64	1·14	1·24	1·15	...	...
Al_2O_3	22·77	13·52	14·09	16·00	20·50	27·50	14·50
Fe_2O_3	2·33	1·13	1·04	0·02	11·91	4·31	2·70
Cr_2O_3	...	nt. fd.	nt. fd.	0·03	...	...	...
FeO	7·22	3·50	7·73	8·02	11·32	3·81	3·40
MnO	0·18	0·22	0·24	0·20	0·26	...	...
(CoNi)O	nt. fd.	nt. fd.	nt. fd.	nt. fd.	nt. fd.	...	...
BaO	0·12	0·03	0·06	trace	nt. fd.	...	...
CaO	1·97	9·11	3·43	12·54	1·27	...	5·04
MgO	3·16	6·28	7·11	9·47	4·18	4·68	8·64
K_2O	2·97	1·50	2·44	0·26	0·72	} 2·60	} 2·60
Na_2O	2·14	0·94	1·10	2·01	1·27		
Li_2O	nt. fd.	trace	trace	trace	nt. fd.	...	...
H_2O at 105° C.	0·10	0·55	0·44	0·07	0·07	0·60	0·80
H_2O above 105° C.	1·87	0·67	0·97	0·41	1·48		
P_2O_5	0·17	0·13	0·13	0·10	0·04	Loss on	Loss on
FeS_2	nt. fd.	0·18	0·05	0·02	0·07	ignition	ignition
Fe_7S_8	nt. fd.	1·70	0·90	0·37	...	=2·60	=1·60
CO_2	0·04	trace	0·03	0·33	nt. fd.	...	...
Totals	100·17	100·08	100·05	100·30	100·09	100·10	99·78

X. Andalusite-schist of Boyndie Bay Group, repeated from p. 450.

XI. Xenoliths in contaminated rock, right bank of River Deveron, 350 yards east of Castle Bridge, Huntly. Analyst, E. G. Radley.

XII. Contaminated rock surrounding xenoliths of Analysis XI. Analyst, E. G. Radley.

XIII. Initial magma of the Huntly Mass, Huntly norite, repeated from p. 480.

XIV. Cordierite-spinel-hornfels, Gallowhill, Arnage, repeated from p. 477.

XV & XVI. 'Shale'-xenoliths in norite of Potgietersrust and Mapoch's Country, South Africa: A. L. Hall & C. Gardthausen, 'Note on some Remarkable Xenoliths of Altered Shale from the Norite of Potgietersrust & Mapoch's Country' Trans. Geol. Soc. S. Africa, vol. xiv (1912) p. 74.

XV. Coarse xenoliths, much cordierite and biotite, little pyroxene, very little felspar.

XVI. Finer-grained xenoliths, rich in plagioclase and rhombic pyroxene, fair biotite, little cordierite.

The chemical change undergone by the Arnage argillaceous xenoliths can be compared with that suffered by the shale-xenoliths (Analyses XV & XVI, Table VI) in the Bushveld norite described by Hall & Gardthausen. The order of abundance of the constituent minerals in the South African xenoliths is cordierite,

[1] H. H. Read, *op. cit.* Chapters vii & viii.

rhombic pyroxene, quartz, biotite, hornblende, plagioclase, magnetite, and disthene. The authors conclude (*op. cit.* p. 78):

'During the intrusion of the Bushveld magma under locally exceptionally active conditions, *i. e.*, accompanied by marked tectonic disturbances, favourable opportunities were afforded of an interchange or transference of material consisting essentially in a removal of alumina and addition of magnesia and lime, whereby entangled masses of shale—xenoliths were intensely metamorphosed, more or less permeated with igneous material, and converted into rocks with highly abnormal mineralogical and chemical composition.'

From this discussion of the two component parts of the contaminated zone, it is justifiable to deduce that there has been a reciprocal reaction or interchange between the initial magma and the xenoliths which results in a relative concentration of, mainly, alumina and potash in the magma and of lime and magnesia in the xenoliths.

I wish to note here some of the observations of other workers on the subject of reaction between xenolith or wall-rock and magma that have come under my notice.

Dr. Herbert H. Thomas [1] finds

'the clearest evidence of the modification of a more or less pure aluminous sediment by permeation of magmatic matter, more particularly by the diffusion of lime, ferrous iron, and magnesia.'

As already noted, A. L. Hall & C. Gardthausen (*loc. cit.*) find a removal of alumina and an addition of magnesia and lime taking place in shale-xenoliths enclosed in the Bushveld norite. The reactions which take place between the argillaceous enclaves and an andesitic magma of Lipari described by Alfred Bergeat [2] are the same as those taking place between the argillaceous enclaves of Arnage and the initial gabbro magma. The same author [3] has shown a very important transfer of material at the margin of the Concepción del Oro granodiorite. Emil Bergeat [4] demonstrates transfer at the contact of banatite and limestone at Vaskö. Reciprocal reaction is indicated by H. J. Johnston-Lavis & J. W. Gregory [5] in their study of the ejected blocks of Monte Somma. R. Brauns [6] finds a reciprocal reaction in the well-known Laacher See rocks, and had stated many years before a belief [7]

[1] 'On Certain Xenolithic Tertiary Minor Intrusions in the Island of Mull (Argyllshire)' Q. J. G. S. vol. lxxviii (1922) p. 255.

[2] 'Der Cordieritandesit von Lipari, &c.' Neues Jahrb. Beilage-Band xxx (1910) p. 575.

[3] 'Der Granodiorit von Concepción del Oro im Staate Zacatecas (Mexiko) &c.' Neues Jahrb. Beilage-Band xxviii (1909) p. 421.

[4] 'Beobachtungen über den Diorit (Banatit) von Vaskö im Banat, &c.' Neues Jahrb. Beilage-Band xxx (1910) p. 549.

[5] 'Eozoonal Structure of the Ejected Blocks of Monte Somma' Sci. Trans. Roy. Dubl. Soc. ser. 2, vol. v (1893–96) p. 259.

[6] 'Die Chemische Zusammensetzung Granatführender Kristalliner Schiefer, Cordieritgestein & Sanidinite aus dem Laacher-Seegebiet' Neues Jahrb. Beilage-Band xxxiv (1912) p. 85.

[7] 'Chemische Mineralogie' 1896, p. 313.

in the reciprocal action of enclave on magma and of magma on enclave.

With regard to the possibilities of diffusion in a magma, it may be pointed out that Dr. N. L. Bowen[1] is of opinion that diffusion through short distances is to be expected, and that reaction-rims about foreign inclusions are readily to be attributed to diffusion.

The abstraction of magnesia and lime from a gabbroic magma recalls the opposite case supplied by the endomorphic changes in granites by reaction with dolomites, described from the Pyrenees and elsewhere in France by A. Lacroix and others.[2]

VIII. Conclusion.

The main purpose of this paper is to establish the following postulate:—the contamination process depends upon *reciprocal reaction* between the gabbro magma and argillaceous xenoliths; the magma becomes more acid, the xenoliths more basic.

I am compelled to leave for future discussion such important points as these:—the significance of the Ardlethen granitic type of product; the existence and history of xenoliths complementary to this granitic type; the possible relation of such xenoliths to the Arnage norite; the operation of gravitative cleansing: and the relation of contamination to petrogenesis. In the abstract[3] of this paper, these points were briefly touched upon. The discussion following the paper deals mainly with them.

* * * * *

In conclusion, I wish to offer my thanks to Dr. J. S. Flett, who has keenly followed the progress of this investigation, and has been at all times ready with advice, discussion, and criticism. I am indebted, too, to Dr. Flett for permitting five analyses of Arnage rocks to be carried out in the Geological Survey Laboratory. I also thank Mr. E. G. Radley, who performed these analyses and many of the others used in this paper. A small party—Prof. R. A. Daly, Prof. C. F. Kolderup, Prof. A. W. Gibb, Dr. J. S. Flett, and Dr. Robert Campbell—has seen the field evidence with me, and I have derived much advantage from the many discussions which took place then. Finally, to my friends of the Scottish Geological Survey, and especially to Mr. M. Macgregor and Mr. J. Phemister, I offer the expression of my sincere gratitude for many helpful criticisms and suggestions.

[1] 'Diffusion in Silicate Melts' Journal of Geology, vol. xxix (1921) p. 316. See also, Kurd Endell, 'Ueber Diffusionserscheinungen in Silikatschmelzen bei Höheren Temperaturen' Neues Jahrb. vol. ii (1913) p. 129.

[2] See especially A. Lacroix, Bull. Carte Géol. France, vol. x (1898–1899) p. 241 and *ibid.* vol. xi (1899–1900) p. 50; A. Michel-Lévy, *ibid.* vol. xviii (1907–1908) p. 193; M. Longchambon, *ibid.* vol. xxi (1910–11) p. 323; E. Weinschenk, 'Vergleichende Studien über den Contact-Metamorphismus' Zeitschr. Deutsch. Geol. Gesellsch. vol. liv (1902), especially pp. 459–61.

[3] Abstracts of the Proceedings of the Geological Society of London, No. 1100, March 23rd, 1923, pp. 63, 64.

Discussion.

Dr. J. S. Flett said that the Author's work and the previous work of Mr. W. R. Watt had shown that in Aberdeenshire and Banffshire we had probably the best example of a province of contaminated basic igneous rocks anywhere at present known to exist. The speaker had had opportunities of studying these rocks, both in the field and in the laboratory. With the Author's conclusions regarding contamination he was thoroughly in sympathy; but, when the Author attempted to show that as end-facies of a contaminated series nearly normal rocks might arise, the speaker confessed that he felt unconvinced, and inclined to the opinion that the xenoliths described could hardly be regarded as a satisfactory mechanism for the chemical exchanges required.

Dr. C. E. Tilley regarded the production of norites and cordierite-norites by the contamination of gabbroid magma as long since established by the observations of Lacroix, Winchell, and Watt. The mechanism of the process was essentially a reaction of the monoclinic pyroxene with aluminium silicate to produce hypersthene and anorthite, the former mineral reacting again with excess aluminous material to produce cordierite. The recognition of norite and cordierite-norite in the Arnage mass as contaminated rocks was, therefore, well founded. By some writers the anorthosite-charnockite family of rocks was denominated a magnesian group; but the analyses of the various members of the family did not support this contention. The presence of rhombic pyroxene in them was favoured by a high alumina content, despite low magnesia and often high lime. The norite of the Arnage mass, however, was a rock strikingly rich in magnesia, and the speaker concurred with the Author in his interpretation of it as a highly contaminated product. The Author, however, went farther, and derived a normal granitic type by contamination. The solution of the problem of the origin of this granite must finally turn on the interpretation of the field evidence; but the speaker was impressed by the freedom of the granite as a whole from xenoliths, a fact which appeared to need careful consideration when the origin of the granite was examined, and he desired to hear the Author's opinion with reference to an alternative view of the granite as a separate intrusion into the roof.

He enquired whether corundum had been discovered as a contamination-product of the Arnage mass. Corundum was an abundant mineral constituting xenoliths of the Cortlandt Series as described by Williams & Rogers; but it was a remarkable fact that cordierite-norites were not recorded from that area, a point demanding further investigation. Was corundum found in direct contact with olivine or hypersthene? The recent work of S. G. Gordon & A. L. Hall on corundum-bearing rocks from North America and South Africa tended, in the speaker's opinion, to throw doubt on the manner of origin of the now classic

corundum-deposits associated with peridotites in North Carolina, as enunciated by Pratt.

The Author, in reply, stated that the contaminated rocks of the Arnage Type and their associated cordierite-xenoliths represent only an early stage of the contamination-process, and it is reasonable to consider that the xenoliths, when introduced into the underlying initial gabbro-sheet, had a concentration of magnesia and lime complementary to the concentration of 'granitic' oxides in the Ardlethen Type of product. It is thought likely that these xenoliths were, at this stage, composed mainly of rhombic and monoclinic pyroxenes.

In answer to Dr. Tilley, the Author stated that, not only did the field-evidence show that the granitic end-product was part of the contaminated rocks, but also bands and patches of similar granitic material occurred throughout the Arnage Type of rock. In reply to Dr. Tilley's queries concerning spinel and corundum, it was stated that the spinel of the granitic end-product occurred associated with cordierite patches. Corundum had not yet been found at Arnage, but had been noted at Huntly in a cordierite-norite of contaminated origin. The Author was gratified to receive Dr. Tilley's support in the view that the magnesia-rich norite of Arnage was by no means an average norite.

18. *The* UPPER ORDOVICIAN ROCKS *of the* SOUTH-WESTERN BERWYN HILLS. By WILLIAM BERNARD ROBINSON KING, O.B.E., M.A., F.G.S. (Read May 16th, 1923.)

[PLATE XXVI—TRILOBITES.]

CONTENTS.

I. INTRODUCTION, AND GENERAL TOPOGRAPHY.

THE area to be described is part of North-Western Montgomeryshire. All place-names mentioned will be found on the 1-inch Ordnance Survey Map, Sheet 136 (Bala), or on the accompanying sketch-maps (figs. 1, 2, & 3, pp. 488, 493, & 496).

Geologically, this area is the western part of the southern flank of the great Berwyn dome of Ordovician strata; but a glance at the geological map shows that in this south-western portion the beds are pinched up so as to form a wedge-shaped south-westerly extension, one flank of which runs with remarkable straightness for several miles. The reason for this straightness of outcrop lies in the fact that in this belt of country the strata are vertical, or have acquired a slight reversal of dip from the south-eastward overfolding.

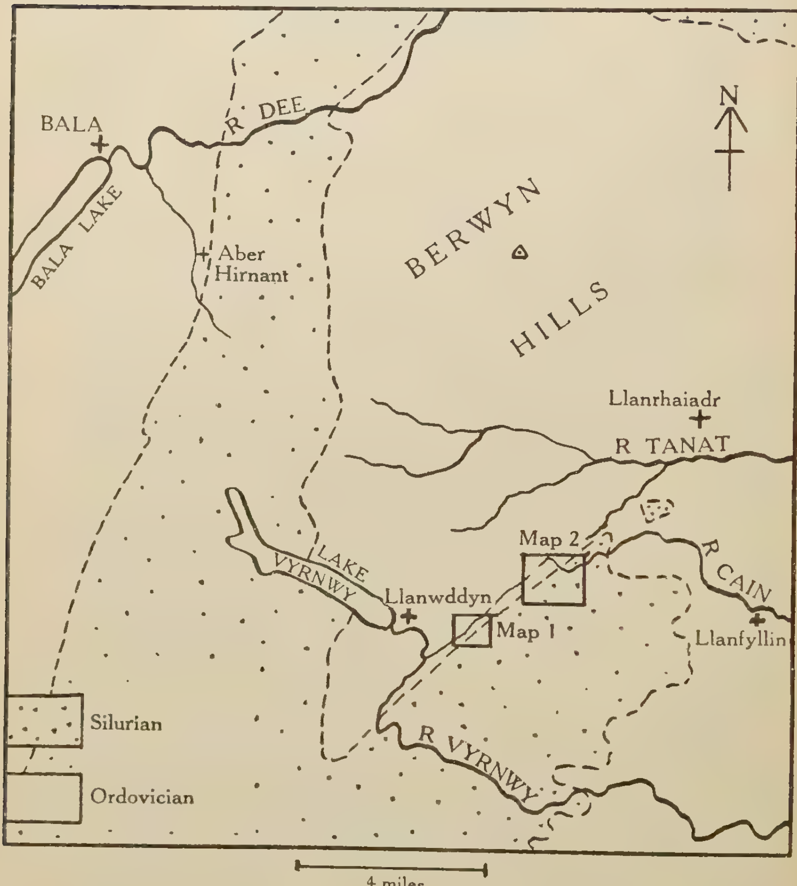
To this cause must also be attributed the parallel arrangement of hill and valley, each band of hard rock standing out as a straight ridge, and each soft bed forming a parallel depression. Thus the sandstones of the Caradocian and the grits and massive mudstones of the Salopian stand out as ridges, while the softer Ashgillian and the shales of the uppermost Caradocian form the marked valley which is followed by the old pack-road connecting the Upper Vyrnwy valley with that of the Tanat.

This strike-valley is drained by various streams. In its north-eastern part to Pen-y-garnedd (Sheet 137) it is drained by a tributary of the Tanat, then for a short distance the headwaters of the Cain drain the water down past Blaen-y-cwm to Llanfyllin, while towards the south-west the Marchnant brook carries off the

water to the River Vyrnwy, which itself follows the line of the Ashgillian for some distance.

Glaciation appears to have had little effect on the general topography, except partly to fill the valleys with a grey-blue

Fig. 1.—*Map of part of the Berwyn Hills.*



[Map 1 is fig. 2, p. 493, and Map 2 is fig. 3, p. 496.]

boulder-clay of local origin. The streams have generally cut through this filling of glacial drift to a depth of some 30 feet, and frequently expose the solid rocks in the valley-bottoms.

II. Previous Literature.

The existing literature on the subject is scanty. Sedgwick crossed this part of the Berwyn country, and noted the inversion of the strata[1]; but the most complete description of the area is given by J. B. Jukes in Ramsay's Geological Survey Memoir on North Wales (2nd ed. 1881); here Jukes remarks (p. 297) that

'the interest to be derived from the study of a locality in which so many and such various physical features are so admirably shown, is heightened by the fact of the limestone and parts of the ash-beds and all the beds about them being crowded with a vast variety of fossils, containing, I believe, all the characteristic species of the formation, and generally in a well-preserved condition.'

This contention is undoubtedly well founded, for the beds are particularly well exposed and remarkably fossiliferous at nearly every horizon.

Following Jukes, there is a paper by D. C. Davies on the phosphorite-deposits of the Berwyn Hills, in which he gives a detailed section of the phosphate-mine at Cwm-gwynen-uchaf[2]; while of late years notes have appeared on the succession and horizon of the beds near Pen-y-garnedd, at the north-eastern end of the area, in the Summary of Progress of the Geological Survey.[3] Much work, however, has been done on the surrounding districts, which enables close correlations to be made. The ground on the east, and even the north-eastern part of the area under discussion, has been surveyed in recent years by the officers of the Geological Survey, largely by Mr. B. Smith and myself. Similarly, rocks of the same age on the northern flank of the Berwyn Hills have been described by Mr. P. Lake & Dr. T. T. Groom,[4] and more recently remapped by Dr. L. J. Wills, while on the Geological Survey, and described by him and Mr. B. Smith in a recent paper read before the Geological Society.[5] On the south-east lies the Welshpool area, worked out by Dr. A. Wade in 1911.[6] On the west is the classical Bala country, of which Miss G. L. Elles has given an excellent account,[7] together with palæontological subdivisions for the shelly facies of the Upper Ordovician rocks, which are proving of wide application and much value.

[1] A. Sedgwick, Q. J. G. S. vol. i (1845) p. 5.

[2] Q. J. G. S. vol. xxxi (1875) pp. 357–67; also preliminary note in Geol. Mag. vol. iv (1867) pp. 251–53. On the 6-inch Ordnance Survey map, the place-name is spelt 'Cwm-gwnen.'

[3] 'Summary of Progress for 1919' Mem. Geol. Surv. 1920, pp. 4–5.

[4] Q. J. G. S. vol. lxiv (1908) pp. 546–95.

[5] *Ibid.* vol. lxxviii (1922) pp. 176–226.

[6] *Ibid.* vol. lxvii (1911) pp. 415–59.

[7] *Ibid.* vol. lxxviii (1922) pp. 132–73; also Geol. Mag. vol. lix (1922) pp. 409–14.

III. The General Succession.

In the area under discussion the rocks fall into the following natural lithological and palæontological divisions :—

Salopian.	Mudstones with grits.
Valentian.	(*a*) pale-grey mudstones, with sandy beds. (*b*) wavy-bedded sandy shales, with thin dark shaly bands, passing down into (*c*) 15 feet of massive bedded fossiliferous sandstone. [*Meristina-crassa* Sandstone.]
	Break.
Ashgillian.	(*a*) leaden-blue blocky fossiliferous mudstone [*Trinucleus-bucklandi* Mudstone], up to 50 feet exposed. (*b*) grey-blue to grey-brown sandy mudstones, fossiliferous throughout, about 1000 feet thick. [*Calymene-quadrata*[1] Mudstones and higher *Phillipsinella* Beds.] (*c*) dark blue-black blocky mudstones, somewhat calcareous, with many fossils about 15 feet. [Lower *Phillipsinella* Beds.]
Caradocian.	(*a*) jet-black graptolitic shales and black limestones, with a phosphate-band 18 inches thick. Total thickness = about 50 feet. [Pen-y-garnedd graptolite-shale.] (*b*) calcareous ashes, with mudstones and irregular limestone-bands, many fossils. [*Orthis-actoniæ* calcareous beds.] (*c*) sandstones and fine sandy mudstones, with an ash-band in the south and west. [*Orthis-alternata* Sandstones.]

IV. Local Details.

A detailed description of the localities where the various beds are well developed may now be given, beginning with the earlier formations.

Caradocian.

Orthis-alternata Sandstones.—Rocks of undoubted Caradocian age form all the high ground from Bryn Cownwy in the south to Bwlch Greölen and the Das Eithen ridge, and the ground immediately north of Pen-y-garnedd, in the north.

The most conspicuous rock-type is a tough, blue-hearted, fine, somewhat muddy sandstone, which occurs in beds measuring up to 2 or 3 feet in thickness, and separated one from the other by beds of varying thickness of sandy blue mudstone. Some of the bedding surfaces of the sandstones and shales are covered with fossils, the commonest forms being :—

Orthis (Heterorthis) alternata Sowerby
O. (H.) alternata var. *retrorsistria* Davidson.
Plectambonites sericea (J. de C. Sowerby) ; Souldey type.
Strophomena (Rafinesquina) expansa (Sowerby).

This is, in fact, the fauna which characterizes the Glyn Gower Sandstones and Allt-ddu Mudstones of the Bala country.[2]

[1] See p. 504.
[2] G. L. Elles, Q. J. G. S. vol. lxxviii (1922) p. 171.

A point to be noted is that the bed of volcanic ash which is well developed in the south-west, in the lower part of the sequence, rapidly dies out to the north-east. This ash may be seen in the road-cutting leading up to the Vyrnwy Dam. The rock is a fine, somewhat impure, pumiceous ash, with a considerable admixture of sedimentary matter. On tracing the bed to the north-east along the vertical limb of the anticlinal fold, we can follow it with ease to within a point 1000 yards north-west of Gwreiddiau, where it forms bold crags, on the western side of the valley which cuts through the ridge to connect the Vyrnwy valley with that of the Tanat at Pen-y-bont-fawr. The ash which forms these crags exhibits several peculiarities. It consists of lumps of ashy material, up to several inches in diameter, embedded in normal blue mudstone; besides the ash, however, there are nodules of calcareous matter the calcite of which is in large plates enclosing numerous dark specks. The bed appears to have been formed from volcanic material under strong current-action. North-east of the valley no beds of ash have been observed at this horizon. This absence cannot be accounted for by faulting, as the Caradoc-Ashgill boundary runs without a break.

The ash may be traced from Llanwddyn for some distance in a northerly direction along the western flank of the Berwyn dome; but I have not traced the ash-bed (as shown on the 1-inch Geological Survey map) into the ashes mapped on the northern side of the dome. There can be no doubt, however, that this bed belongs to a centre of eruption which lay on the west or north-west, rather than to the vents that give rise to the Cwm Clwyd ash, which came from the necks in the neighbourhood of the Carboniferous Escarpment.

Orthis-actoniæ calcareous group.—The sandstones with *O. alternata* pass up without abrupt lithological change into the overlying subdivision. This succeeding group is of a more calcareous nature, and in places, particularly near the summit, passes into fairly pure lenticular limestones. Interstratified with these are beds of impure volcanic ash of no great thickness, and thin beds and wisps of angular fragments of felspar. As a rule, the purer limestones are not highly fossiliferous, and at Pen-y-Garnedd they appear to have been considerably dolomitized; but the associated calcareous shales are in places crowded with fossils which are particularly conspicuous in the weathered, buff-brown, soft, decalcified mudstones.

The most characteristic fossils of this group are:—

Orthis (Nicolella) actoniæ Sowerby.
Platystrophia biforata (Schlotheim); typical large form.
Phacops (Pterygometopus) jukesi (Salter).
Asaphus powisi (Murchison).
Lichas laxatus M'Coy; large form.
Cybele verrucosa (Dalman).
Monticulipora lycoperdon (Say).

A small quarry about 550 yards north-east of the ruin of the

small building called Pwll-y-wrach-isaf, in the Marchnant valley, has yielded many excellent specimens, particularly of *Pterygometopus jukesi*, which Miss Elles found to be characteristic of the calcareous-ash horizon at Bala.

Pen-y-garnedd black-shale group.—At Pen-y-garnedd at the present time the calcareous group is seen to be followed by some 45 feet of jet-black soft shales, with an 18-inch bed of phosphatic material at the base. This section (which will be described in more detail in a Geological Survey Memoir) may be noted here, since it is the best exposure of the phosphate-bed; also the shales above the phosphate-bed have yielded moderately well-preserved graptolites at several horizons.

The change from limestone to shale is not very sudden, for several thin beds of dark shale are intercalated in the upper part of the ashy calcareous beds, marking a fluctuation of conditions of deposit before the black-shale type definitely set in. The same conditions are described by D. C. Davies [1] at the Cwm-gwynen Mine, which he visited when it was being worked; here, however, he notes calcareous shales with echinoderms and brachiopods resting upon a phosphate-bed 10 to 15 inches thick. No mention is made of the thick bed of black shale, and I also failed to identify it in the adit when I visited the mine in 1919. It should, however, be borne in mind that strike-faulting frequently cuts out the black-shale group.

Miss Elles has examined some of the material collected at Pen-y-garnedd, and identifies the graptolites as belonging to species of *Orthograptus*. The occurrence of graptolite-bearing shales at this horizon is of interest, for the forms prove to belong to the *Diplograptus-pristis* Zone of Sweden, which usually is not represented by graptolite-bearing beds in this country.[2] Stratigraphically, therefore, this horizon is the highest part of the *Pleurograptus-linearis* Zone, and as such belongs to the highest Caradocian rocks of Britain. The following species of graptolites have been identified by Miss Elles:—

Orthograptus truncatus var. *pauperatus* Elles & Wood.
O. calcaratus var. *basilicus* Lapworth.
O. aff. *quadrimucronatus* (Hall).
Orthograptus pristis (Hisinger).
Climacograptus minimus Carruthers.
C. styloideus Lapworth.
C. scalaris var. *miserabilis* Elles & Wood.

Besides containing graptolites, these shales yield numerous small horny brachiopods and dwarf hinged brachiopods, among which the following appear to be commonest:—

Plectambonites albida Reed.
Lingula cf. *brevis* Portlock.
Lingula obtusiformis Wade.
Siphonotreta cf. *micula* M'Coy.

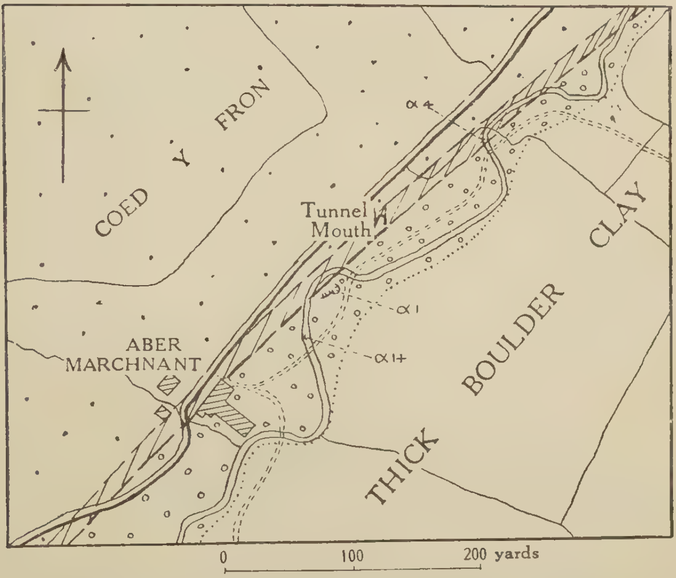
On tracing this zone south-westwards to near Aber Marchnant

[1] Q. J. G. S. vol. xxxi (1875) p. 358.
[2] 'Summary of Progress for 1919' Mem. Geol. Surv. 1920, pp. 4 & 5; also L. J. Wills & B. Smith, Q. J. G. S. vol. lxxviii (1922) p. 186.

farm (α 4, fig. 2), it appears that the shale with poorly-preserved graptolites is thinner; but here are bands of black muddy limestone. These limestones contain a few fossils, mainly hinged brachiopods similar to those of the shales, though as a rule not quite so dwarfed. It was in these beds that the new tunnel for the water-main from Lake Vyrnwy was begun; and a natural exposure may be studied a few yards south-west of the tunnel-mouth, where the limestones form a cliff on the western bank of the stream (north-west of α 1 in fig. 2).

It is believed that this horizon represents the greater part, or more probably the whole, of the Gwern-y-brain Beds of the

Fig. 2.—*Sketch-map 1: Aber Marchnant.*



[The *Phillipsinella* mudstone (Ashgillian) is represented by open dots; the Black Shale Group (Caradocian) by a striped band, and the sandy mudstones (Caradocian) by black dots.]

Welshpool area described by Dr. A. Wade.[1] The fauna in the Gwern-y-brain Beds is exactly identical with, but more varied than, that of the Pen-y-garnedd Shales, and, if we take the two in conjunction, the following points will be noticed:—(*a*) the dwarfed size of all forms; (*b*) the abundance of individuals of a few species; (*c*) the thin-shelled character of the fauna; and (*d*) the abundance of small bellerophons, gastropods, ostracods, and horny brachiopods, together with dwarfed graptolites.

The characters of this fauna clearly indicate conditions unfavourable for the growth of the thick-shelled forms usually found

[1] Q. J. G. S. vol. lxvii (1911) pp. 428–31.

at this horizon. The lithology of the shales and the presence of a phosphate-band point to waters devoid of normal terrigenous sediments, while the manner in which the shales come immediately above, and even interstratified with, very shallow-water deposits show that they cannot be of deep-water origin. Thus the beds were formed in a shallow sea, free from much sediment, yet unfavourable for the normal life of the times: a state which may probably be attributed to lagoon conditions somewhat similar to those described by Mr. E. E. L. Dixon in the Carboniferous rocks of Gower.[1]

Caradoc-Ashgill junction.—At localities where the black shales can be followed up into the overlying strata, as at Pen-y-garnedd and at Aber Marchnant, the passage is seen to be gradual, and there is no sign of unconformity,[2] the black shales merely giving place to dark blue-grey and black blocky mudstones which yield the typical basal Ashgillian fauna that will be noted below. From this it is clear that the black shales occur between the lower part of the *Orthis-actoniæ* Zone and the base of the Ashgillian: that is, they lie on the horizon of the upper part of the *Orthis-actoniæ* Zone of Bala, and therefore represent beds of limestone and calcareous ash on the western side of the Central Wales syncline. The recent work by Miss G. L. Elles[3] rules out any possibility of unconformity between the *Orthis-actoniæ* Beds and the basal Ashgillian (Rhiwlas Limestone), and therefore the Pen-y-garnedd Shales cannot be an horizon that is not present at Bala. It may be noted also that the limestones at this horizon at Bala are sometimes phosphatic and oolitic,[4] and were certainly formed in shallow water.

Ashgillian.

Lower *Phillipsinella* Beds.—Simultaneously with the change from black shales to dark blocky mudstone there is a marked change in the fauna. Instead of graptolites and dwarfed inarticulate brachiopods, an extremely rich and varied fauna makes its appearance. This fauna contains all the typical elements of that of the basal Ashgillian.

In the old quarry 150 yards north-east of Aber Marchnant Farm (α1, fig. 2) dark calcareous blocky mudstones have yielded a large number of excellently preserved fossils. One of the most striking features of the fauna is the small size of the forms and the manner in which numerous individuals of the same species are found in close proximity one to the other: for example, one specimen showing a surface of about 2 square inches shows fragments of the heads of four individuals of a small variety of *Lichas laxatus* M'Coy, while another specimen having a surface of about 1 square inch is practically composed of the heads of *Calymene*.

[1] E. E. L. Dixon & A. Vaughan, Q. J. G. S. vol. lxvii (1911) pp. 525–31.
[2] 'Summary of Progress for 1919' Mem. Geol. Surv. 1920, p. 5.
[3] Q. J. G. S. vol. lxxviii (1922) p. 152.
[4] *Ibid.* p. 142.

This locality may be taken as characteristic of the lowest Ashgillian of the district. It has yielded the following forms:—

Christiania tenuicincta (M'Coy); small form. Abundant.
Orthis (Hebertella) crispa M'Coy.
Plectambonites scissa (Davidson).
Plectambonites quinquecostata (M'Coy).
Rafinesquina subarachnoidea Reed.
Stropheodonta corrugatella (Davidson).
Echinosphæra cf. *litchi* (Forbes).
Echinosphærites cf. *arachnoideus* Forbes.
Agnostus agnostiformis (M'Coy).
Calymene cf. *blumenbachi* var. *drummockensis* Reed.
Calymene aff. *quadrata* sp. nov.
Cheirurus juvenis Salter.
Cheirurus octolobatus M'Coy.
Cheirurus cf. *pseudohemicranium* Nieszkowski.
Cheirurus sp.
(?) Chromus sp.
Cybele cf. *rugosa* (Portlock).
Cybele rugosa var. *attenuata* Reed.
Cybele verrucosa (Dalman).
Cyphaspis megalops (M'Coy).
Illænus bowmanii Salter.
Illænus sp.
Lichas laxatus M'Coy; small form.
Phacops (Acaste) apiculatus Salter.
Phacops (Dalmanites) robertsi Reed.
Phacops (Pterygometopus) brongniarti Portlock.
Phillipsinella parabola (Barrande); very common.
Remopleurides sp.
Staurocephalus cf. *murchisoni* Barrande.
Trinucleus sp.

There are also fragments of many other forms which are too incomplete for determination.

This may be taken as the typical fauna of the lowest dark mudstones of the Ashgillian of this district. There are, however, a few species which appear to be rare or absent here that are common at other exposures, notably *Trinucleus seticornis* Hisinger.

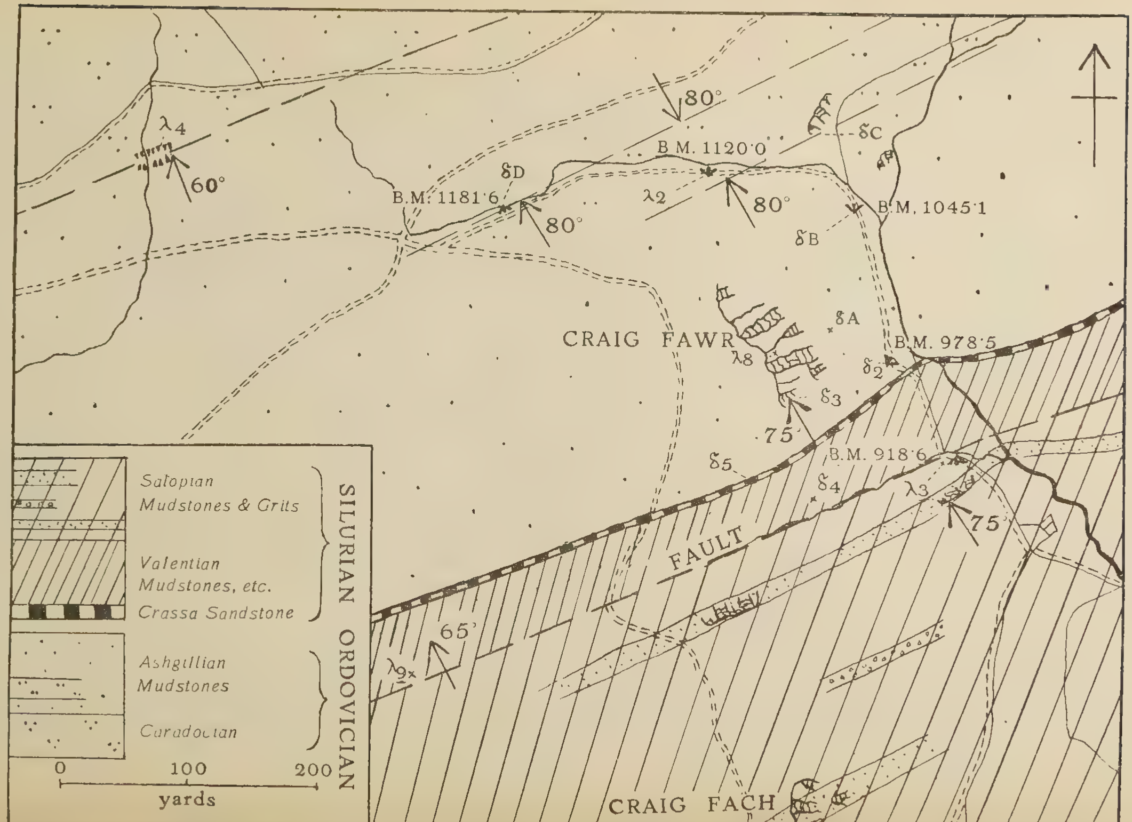
About 15 feet of dark mudstones are seen before they give place gradually to the blue-grey and olive green-grey mudstones of the more normal Ashgillian colouring. The lower part of this series is also highly fossiliferous. The beds are exposed in the bank of the stream on the north side of the ford near Aber Marchnant ($\alpha 1+$, fig. 2); also in the road-cutting immediately south-west of the farm. The fauna of these beds is somewhat different from that of the underlying strata, but certainly belongs to the *Phillipsinella* fauna. Among the fossils found, the following have been identified:—

Orthis (sensu stricto) cf. *playfairi* Reed.
Plectambonites scissa (Davidson).
Strophomena sp.
Lichas sp.
Phillipsinella parabola (Barrande).
Remopleurides longicostatus Portlock (common).
Sphærocoryphe thomsoni Reed.
Orthoceras cf. *audax* Salter.

A marked type of lithology occurs about this horizon, the beds of normal pasty grey-green mudstone becoming full of specks and blotches of dark-blue mudstone. This type of lithology has been found in the lower portions of the Ashgillian throughout the area on the east around Llanfyllin.

The beds immediately above this speckled zone are usually covered by drift, but in the small valley which runs down to Blaen-y-cwm past Craig Fawr (fig. 3, p. 496) the next succeeding strata are magnificently exposed in an almost continuous section along the bridle-path and on the crags of Craig Fawr. In all this area the

Fig. 3.—*Sketch-map 2: Blaen-y-cwm Valley.*



beds are nearly vertical, and thus fairly accurate measurements of the thicknesses are easily obtained.

On leaving the watershed the bridle-path, which follows the stream, runs obliquely across the strike. The beds which are exposed here (δ D, fig. 3) are about 400 feet above the base of the Ashgillian, and from this point the beds are highly fossiliferous for another 100 feet. the most striking feature being the presence of numerous forms of bryozoa, particularly :—

Monticulipora fibrosa M'Coy.
Monticulipora lycoperdon (Say).
Ptilodictya dichotoma Portlock.
Phyllopora sp.

Other fossils from this horizon are :—

Pleurocystis rugeri Salter.
Christiania tenuicincta (M'Coy).
Leptæna sp.
Orthis sp. α. [See p. 507.]
Orthis.
Stropheodonta corrugatella (Davidson).
Agnostus agnostiformis (M'Coy).
Cybele rugosa var. *attenuata* Reed.
Cheirurus juvenis Salter.
Illænus bowmanii Salter.
Illænus sp.
Lichas laxatus M'Coy.
Phillipsinella parabola (Barrande).
Pterygometopus sp.
Proetus (?).
Remopleurides nicholsoni Reed (common).
Trinucleus sp.

The rock which constitutes this horizon is a slightly sandy grey-blue mudstone, which weathers to a greenish-grey or buff colour The fossils weather out as casts filled with brown rottenstone.

About the turn of the path where two small valleys meet to run nearly due south, the beds begin to take on a more massive nature, and to become rather more arenaceous; but they always remain essentially mudstones, owing to the extremely fine grain of the sand-particles. In colour they are the same as the underlying beds. Fossils are usually plentiful and well preserved. One excellent locality was found on Craig Fawr (λ 8, fig. 3), where several complete specimens of *Calymene* have been obtained. Other localities (δ B, δ A, δ 2, δ 3) are shown on the map (fig. 3). At all these localities the fossils seem to be similar, the most characteristic forms being *Calymene quadrata* sp. nov. and large *Christiania tenuicincta.* The following is a list of the forms found at the above-mentioned localities, and others situated in the same stratigraphical position :—

Atrypa cf. *marginalis* Dalman.
Christiania tenuicincta (M'Coy); large rotund form.
Do. do. ; elongate form.
Leptæna rhomboidalis var. γ Reed.
Meristina cf. *crassa* (Sowerby); one specimen.
Orthis calligramma Dalman.
Orthis sp. α. [See p. 507.]
Plectambonites sericea, type.
Plectambonites aff. *rhombica* (Davidson).
Plectambonites sp. nov.
Rafinesquina subarachnoidea Reed.
Strophomena sp.
Calymene quadrata sp. nov. [See p. 504.]
Cybele loveni Linné.
Illænus.
Lichas geikei var. nov. [See p. 505.]
Lichas sp.
Pterygometopus brongniarti var. nov. [See p. 506.]
Remopleurides nicholsoni Reed.
Sphærocoryphe thomsoni Reed.
Staurocephalus cf. *murchisoni* Barrande.
Stygina latifrons ? (Portlock).
Trinucleus cf. *bucklandi* Barrande.
Phyllopora.
Ptilodictya dichotoma Portlock.
Monticulipora fibrosa M'Coy.
Conularia planiseptata Slater.
Conradella cf. *fimbriata* Ulrich & Schofield.
Orthoceras sp

The next section of interest is that at the head of the first tributary of the Marchnant stream coming from the south off Pen-y-bylchau, which joins the main stream near point 1117 on the bridle-path (1-inch Ordnance Survey map).

The tributary stream rises in some boggy ground, and cuts a small gorge through the upper slopes of the valley-side: here are exposed several hundred feet of strata, the lower beds being exactly similar to those described above and yielding *Calymene quadrata* in profusion, with the usual assemblage of fossils. In this section, however, these beds are followed by some 45 feet of very tough, blue-grey, blocky mudstones almost free from sandy material, and weathering with orange-coloured rusty joints. They have yielded a small, but excellently preserved fauna, the commonest forms being the following (loc. δ 6, fig. 4, p. 499):—

Trinucleus bucklandi Barrande (common).
Stygina latifrons (Portlock).
Cybele loveni Linné.
Illænus.
Remopleurides (?).
Plectambonites cf. *quinquecostata* (M'Coy).

Of these the *Trinucleus, Stygina*, and *Illænus* are represented by complete individuals.

Ordovician-Silurian Boundary.

Above the mudstones with *Trinucleus* just described there is a sudden and complete change of lithology to a massive brown sandstone some 15 feet thick. When fresh, this sandstone is somewhat calcareous and blue-grey in colour; but, when it is weathered, certain beds are seen to be crowded with brachiopods and crinoid-stems.

The exact horizon of this sandstone is open to doubt, but it obviously indicates some change in the relationship between land and sea. On cartographical evidence there would appear to be a slight unconformity at the base of the sandstone, for it is significant that there are 45 feet of blocky mudstones with *Trinucleus* between the sandstone and the *Calymene-quadrata* Beds at the δ 6 locality (see fig. 4, p. 499); and apparently the sandstone rests directly upon the *Calymene-quadrata* Beds at the Ordnance bench-mark 978·5 in the Blaen-y-cwm valley (δ 2, fig. 3, p. 496), about half a mile distant. Both faunistically as well as lithologically, the break is complete. By far the commonest fossil is *Meristina crassa* (Sowerby), but associated with it are:—

Orthis sagittifera M'Coy.
Atrypa marginalis Dalman.
Leptæna sp.
Strophomena sp.
Platystrophia biforata var. *fissicostata* (M'Coy).
Myelodactylus.

The sandstone may be traced almost continuously in a nearly straight line, from above the Vyrnwy near Glan-y-rhyd to beyond the Blaen-y-cwm valley, a distance of 3 miles. It is seen at Rhos-fawr, 3 miles west-north-west of Llanfyllin.

South-west of Llanfyllin, on Allt Gôch, a peculiar grit with basal calcareous conglomerate is found, lying upon Ashgillian beds which contain *Calymene quadrata*, etc. This grit is also fossiliferous, yielding corals and a few brachiopods. It may be noted that in Salter's Catalogue[1] fossils are recorded from this locality, the lithology of such species as are preserved showing that they come from this conglomerate. The following forms are noted:—*Heliolites tubulata* (Lonsdale), *Favosites* sp., and *Pentamerus rotundus* Sowerby. The last-named is, however, an extremely poor specimen, and even the generic determination is uncertain.

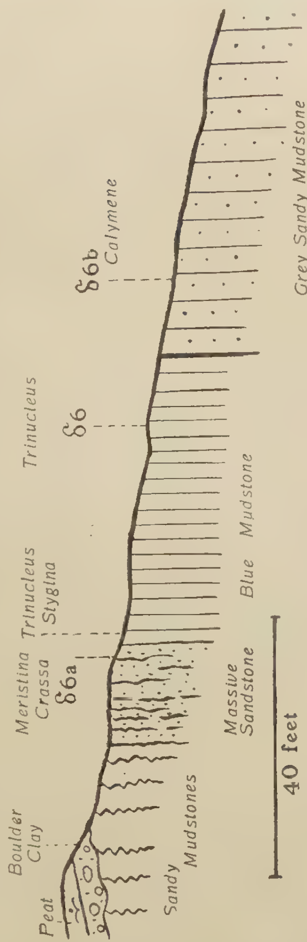


Fig. 4.—*Section at the head of the first tributary on the south side of the Marchnant Valley (strata vertical).*

That the sandstone (with *Meristina crassa*) and the grit lithologically belong to the overlying beds is shown by their passage upwards into the higher beds: blue-shale wisps becoming increasingly more abundant, until the whole has passed into peculiar wavy-bedded sandy shales, with partings of dark-blue shale. Unfortunately, these beds have yielded no fossils.

The sudden change in lithology from the Ashgillian mudstones to the sandstone, and the gradual passage of the sandstone into the overlying beds, together with the presence of such large numbers of *M. crassa* and other *Meristinæ* and the apparent absence of *Phacops-mucronatus* Beds, would seem to corroborate the suggestion that there is a slight unconformity between the sandstone and the Ashgillian, and to indicate a Silurian (Lower Valentian) age for the sandstone, although some of the fossils appear to occur in the higher Ashgillian beds elsewhere.

[1] J. W. Salter, 'Catalogue of the Collection of Cambrian & Silurian Fossils, &c.' Cambridge, 1873, pp. 73–79.

Silurian.

It is not proposed to describe the Silurian rocks in detail, but it may be noted that in the area under consideration much of the Upper Valentian appears to be missing by strike-faulting, although a few graptolites of Middle Gala age have been found. The Salopian is, however, well developed, and forms high ground. There are numerous beds of coarse grit in the south-west of the area, and in the Blaen-y-cwm valley three beds may still be distinguished, one forming the bold crag of Craig Fâch, and another forming the crags immediately south of λ 3 and Ordnance bench-mark 918·6 (fig. 3, p. 496). This is the lowest grit, and is the only one that can be traced north-eastwards. This grit also thins out so rapidly that in the stream-section, just before the Silurian is faulted out by the Bwlch-y-greölen Fault, it is represented by a thin sandstone. East of that point no grits appear at this horizon.

V. Correlations with Neighbouring Areas.

(*a*) Welshpool.—The lower beds have much in common in the two areas; but, as the main land-mass appears to have lain on the east, the beds at Welshpool are liable to be somewhat coarser. Much of the Gaer-fawr Grit series is extremely like the Caradocian sandstones of the Berwyns, and there can be little doubt that the Gwern-y-brain Beds are of the same age as the Pen-y-garnedd Shales. These have been shown to be much more closely related to the Caradocian than to the Ashgillian. The fauna recorded from the Gwern-y-brain Beds is peculiar; but the absence of the typical basal Ashgillian as developed in the Marchnant Valley made correlation difficult. It would now appear, however, that the Ashgillian is entirely missing in the Welshpool area, and, if ever deposited, was eroded prior to the deposition of the Powis Castle Conglomerate.

(*b*) Glyn Ceiriog.—The connexion with the Glyn Ceiriog area is naturally close. Volcanic action was more rife in the Glyn area in Caradocian times, the northern flank of the Berwyn Hills coming under the influence of both the western or north-western vents and the vents situated on the south-east near the Carboniferous Escarpment; while the South-Western Berwyns only received small showers of ash, presumably from a north-westerly direction.

The strike-fault at the base of the Dolhir Beds obscures the sections at the base of the Ashgillian; but it is clear that the Blaen-y-cwm Beds are the equivalent of the Pen-y-garnedd Shales,[1] while perhaps the Ty'n-y-twmpath Beds are contemporaneous with the dark Lower Ashgillian of the Marchnant Valley.

[1] See L. J. Wills & B. Smith, Q. J. G. S. vol. lxxviii (1922) p. 186.

Correlation of the Upper Ordovician and Valentian of the Berwyn Hills with the Succession in other Areas.

	Welshpool.	South-Western Berwyn Hills.	Glyn Ceiriog.	Bala.
Valentian.	Powis Castle Conglomerate.	Pale-grey sandy mudstones.	Fron Frys Slates.	Cwm-yr-Aethnen Shales.
		Wavy-bedded sandy shales.		
		Meristina-crassa Sandstone.		Hirnant Beds.
			Corwen-Glyn Grit.	
Ashgillian.	Missing.	Missing.		Foel-y-Ddinas Mudstones, containing *Phacops mucronatus*.
		Trinucleus-bucklandi Mudstones.		
		Sandy mudstones with *Calymene quadrata*.	Dolhir Beds.	Moel-fryn Sandstones.
		Sandy mudstones, spotted mudstones, dark blocky mudstones. } Beds with *Phillipsinella parabola*.	Ty'n-y-twmpath Beds.	Rhiwlas Beds, yielding *Phillipsinella parabola*.
Caradocian.	Gwern-y-brain Beds.	Black graptolite-shales and dark limestones of Pen-y-garnedd. Limestones, ashes, and calcareous mudstones containing *Orthis actoniæ*.	Blaen-y-cwm Beds. Ash.	Calcareous-ash horizon and limestones, with *Orthis actoniæ*.
	Gaer-fawr Grits, etc.	Sandstones and mudstones containing *Orthis alternata*, with an ash-bed.	Bryn Beds. Ash.	Allt-ddu Mudstones. Ash and Glyn Gower Sandstones, with *Orthis alternata*.

The Glyn Grit fossils do not appear to be the same as those from the *Meristina-crassa* Sandstone, and it would seem that the grit was being formed at a time when the Marchnant Valley was actually above water, or at any rate undergoing submarine erosion. The *M.-crassa* Sandstone would be the deposit formed on re-submersion or renewal of sedimentation, and therefore correspond in time with the upper part of the Corwen-Glyn Grit or probably somewhat later.

(*c*) Bala.—In many respects the correlation with the Bala district is the easiest to make, for the faunal groups suggested by Miss G. L. Elles are found to be applicable. Among the points of detail, the fact that the ash-beds in the South-Western Berwyn Caradocian are much fewer and thinner is worthy of note.

The lithological type of the main mass, as well as the fauna, of the *O.-alternata* Sandstones is extremely similar in the two areas. In the *O.-actoniæ* Beds, however, the similarity is less marked. In the lower portion, in the Marchnant Valley, there are only slight signs of contemporaneous volcanic activity; but the palæontological evidence leaves no room for doubt as to the correlation with part of the calcareous-ash group at Bala. At that locality, however, there is no black graptolite-shale group corresponding to the Pen-y-garnedd Beds; presumably, if the theory of the lagoon origin of the black shales be correct, the Bala area lay outside the barrier which separated the open sea from the lagoon waters.

In Ashgillian times conditions were again equalized; but no limestone comparable with the Rhiwlas Limestone was deposited in the Marchnant Valley.

Some doubt may be expressed as to the correlation higher in the sequence, for no fossils comparable with those from the mudstones of the Marchnant Valley have been found in the Moel-fryn Sandstones of Bala. The *M.-crassa* Sandstone appears to be about the horizon of the somewhat more open-water beds represented by the Hirnant Group.

VI. General Summary of the Sequence of Events in the South-Western Berwyns.

During early Caradocian times a shallow sea covered the district, which was gradually sinking to keep pace with the accumulation of the sands and silts that were being brought into the region. At one period volcanic ash from the north-west reached this part of the Berwyns in sufficient quantities to form a definite ash-bed, while at other times much fine volcanic material was mixed with the normal terrigenous sediments.

The fauna at this period consisted largely of brachiopods, together with a few trilobites. In later Caradocian times the sedimentation was more calcareous, and again fragments of volcanic ash (mainly in the form of bits of felspar) reached the area; life was extremely abundant in the shallow seas, the brachiopods and trilobites being

of conspicuously large size. Then came a marked change in the physical conditions, which seems to have affected the type of deposit and fauna; for, instead of limestones and mudstones, with large well-grown forms, black limestones and shales occur containing dwarfed graptolites, inarticulate brachiopods, and small thin-shelled mollusca.

This change is thought to be due to the formation of an enclosed lagoon between the land on the east and the open shallow sea on the west. Whatever these conditions may have been, they were of comparatively short duration, and soon gave place to a more normal type of sedimentation with the incoming of the Ashgillian fauna. This fauna was composed of numerous small (but highly, or even excessively) developed forms, which flourished in the Lower Ashgillian muds. This fauna seems to be exotic, rather than descended from the former indigenous Caradocian fauna.

During the whole of Ashgillian time, as represented in this district, the sea appears to have remained fairly shallow, and supported a large fauna—trilobites, polyzoa, and brachiopods being the commonest forms, with a few cystidea and gastropods.

The basal sandstone of the Silurian indicates the first break in the succession, and it is probable that, after the deposition of the mudstones with *Trinucleus bucklandi* and perhaps other beds corresponding to the *Phacops-mucronatus* Beds, the area was subjected to tilting, the uplift being greatest in the Welshpool district, slight in the Vyrnwy district, and at Glyn Ceiriog and Corwen possibly not raising the sea-floor enough for erosion, but only bringing that region within reach of the sandy sedimentation which gave rise to the Glyn-Corwen Grit. When submersion and deposition again began in the Vyrnwy area the shallow-water massive *Meristina-crassa* Sandstone was laid down, and with deepening water came the overlying Valentian shales and mudstones; while, in the neighbourhood of Welshpool, the greater elevation and more prolonged period of denudation removed the whole of the Ashgillian, the sea not entering that area until Upper Valentian times.

It appears, therefore, that the South-Western Berwyn area throughout Upper Ordovician times was one of shallow water, but also one in which the conditions of deposition and supply and type of sediment varied considerably from time to time; throughout, however, it was one well able to support a large and varied fauna, the remains of which can be seen in the rocks as now exposed.

VII. Palæontological Notes.

General Remarks.

The Caradocian fauna, with the exception of that of the highest beds, is the typical North Welsh fauna of the age. The peculiarities of the fauna of the highest Caradocian (black-shale group) have already been noted.

The fauna of the lowest Ashgillian is that of the Rhiwlas Limestone and Mudstone; but, in the higher Ashgillian beds, the fauna is much richer than in the western parts of North Wales, and it is here that several new forms of interest are found.

It will be noticed that, in the lists of fossils from the *Calymene-quadrata* Beds a large number are identified with forms found in the 'Starfish Band' of the Drummock Group at Girvan.

The fauna of the *Trinucleus-bucklandi* Mudstones appears to belong to the *Calymene-quadrata* fauna, and not to the *Phacops-mucronatus* fauna.

The stratigraphical evidence for placing the *Meristina-crassa* Sandstone in the Silurian has already been noted; but, from the point of view of the fauna, there are difficulties. If, however, Miss Elles's contention as to the age of the Hirnant Beds be admitted, then there would be little doubt that the *M.-crassa* Sandstones are also Silurian; for the species (apart from new forms) are either found in the Hirnant Beds, or in the normal Lower Valentian. On the whole, therefore, the evidence in this area supports the ascription of a Silurian age to the Hirnant Beds.

Description of Fossils.

CALYMENE QUADRATA sp. nov. (Pl. XXVI, figs. 1 & 2.)

Description.—The general outline is that of a roundly truncated inverted cone. The head-shield is a quarter of the length of the whole, and presents the general appearance of being wide and short. The glabella is inflated, and its width, from the outside of the basal lobes, is equal to, or somewhat greater than, its length; while the quadrate form of the frontal portion is sufficiently distinctive to suggest the name *quadrata*. The whole surface shows a fine granulation, which is equally developed on young and on adult individuals. The basal glabellar lobes are large and round, while the second and third lobes are much smaller and of nearly equal size. This circumstance, together with the extreme straightness of the anterior margin of the glabella, accounts for the almost square outline of the anterior half of the glabella. The frontal border is of the concave flattened type (as in *C. planimarginata* Reed); but, owing to the inflated nature of the glabella, the margin only rises to about half the height of the glabella. The anterior margin, when seen from above, is straight, or even slightly incurved towards the glabella. The eyes are small, situated opposite the second glabellar lobe, and raised to about the same height as the glabella, thus leaving a deep, slightly concave, axial furrow between the raised fixed cheek and the glabella. A marked pit is observable in the axial furrow, somewhat in front of the third glabellar lobe. The rostral suture is seen to run just on the under side of the raised frontal margin to a position immediately in front of the eye; the anterior part of the facial suture joins this point to the eye in an almost straight line. At the eye, the lateral part of the facial suture makes a right

angle with the anterior portion, from which point it runs in a falling curve to the rounded genal angle.

The four complete specimens each have twelve thoracic segments. The axis is broad and arched, joining the pleuræ at about 100°; the axial half of the pleura lies horizontal, while the marginal half is sharply bent down to within 15° of the vertical.

The outline of the pygidium is that of a bent bow (with cord taut), the margins of the pleural portions being almost straight lines. The axis is well defined, with usually four well-marked rings and a large, broad, somewhat flat, posterior segment. The pleural portions are well defined. Viewed from behind, the pygidium shows a marked arching of the border towards the axis.

The hypostome is of the normal *Calymene* type, so far as could be judged from an imperfect specimen preserved in place in a glabella.

The dimensions of the holotype, in millimetres, are as follows:—

Total length	21	Greatest width	17
Head-shield; length	7	Width (at the genal angles) .	17
Thorax; length	9·5	Width (anterior segment) ...	15·5
Pygidium; length	4·5	Width	10

The holotype is preserved in the Museum of Practical Geology, Jermyn Street, London, under the registration-number 31742–43.

Related forms.—This species has much in common with *Calymene planimarginata* Reed (=*Senaria* of Salter in part). This is indicated by the shape of the frontal margin and the relatively great width of the glabella. It is easily distinguished from *C. planimarginata* by the squareness of the glabella, and by the almost equal and small size of the 2nd and 3rd glabellar lobes; the glabella is also more inflated in the new species. Another form that appears to be related is *Calymene caractaci*, which usually comes in the highest Caradocian. *C. caractaci*, however, has a much narrower glabella and more graded glabellar lobes. A specimen from the lowest Ashgillian of this district appears to be intermediate between *C. caractaci* and *C. quadrata*.

Horizon.—*Calymene quadrata* has been found in the Ashgillian in the higher beds with *Phillipsinella parabola*, and is extremely abundant in the sandy mudstones of the higher part of the Ashgillian in the South-Western Berwyns, where it has been taken as an index-fossil for a group of strata. Among the specimens found are four full-grown and three young complete individuals, together with numerous isolated head-shields.

LICHAS GEIKEI Etheridge & Nicholson, var. (Pl. XXVI, fig. 3.)

A single example of a minute pygidium belonging to a *Lichas* of the group of *L. geikei* was obtained from the lower part of the *Calymene-quadrata* Beds at 6A on Craig-fawr (see fig. 3, p. 496). The pygidium is subquadrilateral in outline, flat, with a well-raised axis extending over half the length of the pygidium, ending bluntly, but continued as a narrow post-axial ridge to the median

notch of the posterior margin. Three well-developed axial rings are preserved on the anterior part of the axis. The lateral parts of the pygidium consist of three pairs of pleuræ similar to those of *L. geikei*; but the first two have the median pleural furrow even more strongly developed. All pleuræ extend to beyond the margin, leaving marked notches in the border. Surface ornamented by fine granules.

Dimensions.—Width of pygidium = 3·5 mm.; length = 2·6 mm.

Phacops (Pterygometopus) brongniarti Portlock, var. (Pl. XXVI, figs. 4 & 5.)

An almost complete enrolled specimen was obtained from the higher part of the *Calymene-quadrata* Beds on Craig-fawr (δ 3 locality, fig. 3, p. 496).

The head-shield is very similar to that of *Pt. brongniarti* Portlock, the only differences being variations in intensity of character rather than in shape: thus, the neck-furrow and groove on the fixed cheek at its junction with the eye seem to be less developed in this specimen, while the anterior (cat's ear) glabellar lobe is rather more pointed anteriorly. The pygidium shows, however, considerable differences; the variety is distinctly pointed, while the pleuræ, although clearly but not deeply marked off one from the other, show no signs of the bifurcation which Portlock notes as one of the characteristics of his species.

Dimensions in millimetres.

Glabella; length	10
Glabella; width (genal angle)	17
Pygidium; length	10
Pygidium; width	14

As only one specimen of this form has been found, it is probably advisable to consider it as a variety of Portlock's species, until other specimens have been obtained and we can see whether the characters noted above are constant.

Christiania tenuicincta (M'Coy).

This is one of the most characteristic fossils of the Ashgillian of the area. The forms in the lower *Phillipsinella* Beds are small (7 to 8 mm.) and generally of the same length as width; but, in the higher beds (*Calymene-quadrata* Beds), they attain much larger dimensions, and tend to group into two types: (*a*) elongate form and (*b*) rotund form.

Individuals gave the following measurements in millimetres:—

(*a*) Length = 19; width = 14.
(*b*) Length = 13; width = 15.

This species appears to be almost restricted to the Ashgillian, and it should be noted that the specimen figured by Thomas

x 2·5.

1

2

x 2·5.

3

x 6.

x 2·5.

4

5

L. LAMBERT DEL.

ASHGILLIAN TRILOBITES FROM THE BERWYN HILLS.

Davidson[1] from Rhos-Fawr Llanfyllin is almost certainly from the Ashgillian (*Calymene-quadrata* Beds) and not from the Lower Llandovery as stated; similarly, his specimens from Lledfron Llanfyllin[2] are also Ashgillian (*Phillipsinella* Beds) and not Caradocian.

ORTHIS (DALMANELLA) sp. *a*.

This form is, probably, included in some of the fossil lists as *Orthis crispa* vars.; but it lacks ornamentation on the ribs, and only has it in the grooves. Here, however, the ornamentation does not consist of simple laminæ, but of a series of honeycomb-like pits arranged in longitudinal groups. The ribs bifurcate generally once, at about half their length.

The shells are generally fragmentary, and no internal structures have been obtained; but the ornamentation is easily distinguished, and the form appears to be characteristic of the higher *Phillipsinella* Beds and the lower part of the *Calymene-quadrata* Beds.

In conclusion, I have to express my thanks to Prof. J. E. Marr and to Miss G. L. Elles for much help and useful criticism; also to Prof. O. T. Jones for examining and naming some of the brachiopods.

EXPLANATION OF PLATE XXVI.

Trilobites from the Ashgillian (*Calymene-quadrata* Beds) of the Blaen-y-cwm valley, 5 miles west-north-west of Llanfyllin (Montgomeryshire).

[The locality-letters are shown in the map, fig. 3, p. 496.]

Fig. 1. *Calymene quadrata* sp. nov. Holotype from λ 8 on the crags of Craig Fawr, Blaen-y-cwm valley, Llanfyllin. Specimen No. 31742–43. Museum of Practical Geology, Jermyn Street. $\times$ 2·5.

2. Do. A more perfect head, without free cheeks; δ 3, same locality. Sedgwick Museum, Cambridge. $\times$ 2·5.

3. *Lichas geikei* Nicholson & Etheridge, var. Pygidium from δA, same locality. Sedgwick Museum, Cambridge. $\times$ 6.

Figs. 4 & 5. *Phacops (Pterygometopus) brongniarti* Portlock, var. Two views of an enrolled specimen from δ 3, same locality. Sedgwick Museum, Cambridge. $\times$ 2·5.

[1] 'Monograph of the British Fossil Brachiopoda' vol. iii, Pal. Soc. 1864–71, pl. xlvii, fig. 18.

[2] *Ibid.* pl. xlvii. figs. 8–15.

[For the Discussion, see p. 541.]

19. *The* Geology *of the* District *around* Corris *and* Aberllefenni (Merionethshire). By William John Pugh, O.B.E., B.A., F.G.S., Professor of Geology in the University College of Wales, Aberystwyth. (Read May 16th, 1923.)

[Plate XXVII—Map.]

Contents.

I. Introduction.

The area described in this paper lies south-east of the main mass of Cader Idris, about the villages of Corris and Aberllefenni. The north-western boundary is the great fault-valley of Tal-y-llyn, lying at the foot of Cader Idris, and along which runs the road from Towyn to Dolgelly, over the picturesque pass called Bwlch-llyn-bach. The south-eastern boundary lies parallel, at a distance of some 3 or 4 miles. The area extends from the high ground about Taren y Gesail in the west to Mynydd Dolgoed and Waen Oer in the east, a distance of about 6 or 7 miles.

The district lies mainly within the county of Merioneth, but a part extends over the border into Montgomeryshire. It is included in the 1-inch Ordnance Survey Maps, Sheets 149 & 150, in the 6-inch maps of Merionethshire, Sheets XLII, N.E. & S.E., XLIII, N.W., XXXVII, S.E., XXXVIII, S.W., and in the Geological Survey Map, Old Series, 1-inch Sheet 59, N.E.

The area is drained almost entirely by tributaries of the River Dyfi (Dovey), which lies some 4 or 5 miles south of Corris. The most important stream traversing the area is the River Dulas, which passes through the villages of Corris and Aberllefenni. It is along this valley that the main road from Machynlleth reaches Corris and Aberllefenni, and it is also followed by a light railway which affords alternative communication between the above-mentioned localities.

The region is one of some economic importance, and contains important slate- and slab-quarries, which have been worked for a great number of years ; it is stated that the quarries at Aberllefenni were opened about the year 1500.[1] The area forms part of an

[1] D. C. Davies, 'A Treatise on Slate & Slate-Quarrying' 1878, p. 64.

extensive slate-quarrying region which extends from near Towyn in the west as far as Dinas Mawddwy in the north-east.

Except for slate-quarrying, the main occupation is sheep-farming, there being comparatively little ground capable of tillage.

Physical Features.

The area forms part of a deeply dissected plateau, which attains an altitude of 1200 to 1800 feet; but locally greater heights are reached, as, for example, at Taren y Gesail, south-west of Corris (1961 feet), and Waen Oer, north-east of Aberllefenni (over 2000 feet).

Many of the streams show well-marked features of rejuvenation, a characteristic which is common to many of the streams comprised within the Dyfi drainage-area. The rejuvenation is well seen in some of the tributary valleys of the River Dulas, and particularly those lying south of Corris. The upper part of these tributary valleys is wide and floored with boulder-clay, while, lower down, the stream suddenly plunges into a steep-sided and wooded gorge. Such characteristics, to cite one example, are well shown in the small stream called Nant y Daren, where the change in character occurs about the 600-foot contour-line, and may be recognized at once by examination of a large-scale map. In the field this change in topography is well marked.

The area exhibits many of the characteristic features resulting from glaciation; for instance, the broad, straight valley of the Llefenni (above Aberllefenni), the small cwms of Taren y Gesail, etc.; but the district is comparatively free from glacial drift. Where glacial deposits do occur, they are almost entirely confined to the floor of the larger valleys and the upper parts of the tributary or smaller valleys. As a result, rock-outcrops are numerous over practically the whole area. This, coupled with the numerous quarries and trials for slate, makes it possible to survey the district with a considerable degree of accuracy.

II. History of Previous Research.

There are comparatively few references in geological literature to this area, and little detailed work appears to have been attempted previously.

In 1847, Adam Sedgwick [1] described a section from a point on 'the south side of the Barmouth estuary over the top of Cader Idris, and thence over the ridges of Arran y Gesail [2] to the valley above Machynlledd.' He states that such a section 'will be nearly transverse to the general strike of the country.' Sedgwick divided the rocks along this line of section into a number of groups, based principally upon their lithological characters; but it is interesting to observe that he recognized the two great groups of rocks in this

[1] Q. J. G. S. vol. iii (1847) pp. 147–48.

[2] Now spelt on the Ordnance Survey Maps 'Taren y Gesail.'

district: namely, the Upper Ordovician lying above the volcanic rocks and the Valentian, especially the Upper Valentian or Tarannon Series, which covers so large an area between Corris and Machynlleth, and the rocks of which are 'violently contorted'.

Sedgwick included 'a part of the slate series on the south flank of Cader Idris, descending towards the country near Machynlledd' in his 'Upper Cambrian slate group, or the Trilobite group, or (geographically) the Bala group' (*op. cit.* pp. 157, 158).

In 1852, Sedgwick[1] again referred to this area. In giving a classification of the Lower Palæozoic rocks, he stated that the 'Bala Group' which overlies 'the Arenig slates and porphyries' is of great thickness, and that the lower part of the group is finely developed on the south-eastern flanks of Cader Idris.

In the same year appeared the Geological Survey Horizontal Section No. 26, which indicated the general arrangement of the rocks along a line through Cader Idris south-eastwards, and passing between Corris and Aberllefenni.

In the following year, Sir Andrew Ramsay[2] stated that Bala and Llandeilo rocks overlie the volcanic rocks of Cader Idris, and occupy the country on the south-east. He comments upon their unfossiliferous nature.

In 1855, the Geological Survey Map[3] of the Cader Idris country was published. The rocks of the Corris-Aberllefenni area are indicated as being of Lower Silurian age. Along the south-eastern margin of the volcanic rocks the symbol 'b^2' may be observed, indicating 'Llandeilo and Arenig' beds, while all the country on the south and south-east is labelled 'b^3', indicating 'Caradoc or Bala' rocks.

In 1872, the Rev. W. S. Symonds[4] referred briefly to this area, and, in describing the unfossiliferous nature of the rocks, stated that they appeared 'to resemble, rather the nearly unfossiliferous grits of the Lower Llandovery series, than the fossiliferous Caradoc strata of Bala and other districts.'

Six years later appeared Mr. D. C. Davies's 'Treatise on Slate & Slate-Quarrying' (1878, pp. 61–64), and, so far as I am aware, this contains the most detailed description of the rocks of this area that has been published. Davies classified the rocks of the Corris area as belonging to the Llandeilo Series, and considered it erroneous to correlate them with the Bala Group. He describes the slate-beds in some detail, and gives a horizontal section of the strata. He recognizes the slate-bed locally known as the 'Narrow Vein', and states that it is overlain by the 'Hard Rock'. This latter group is, according to Davies, overlain by the 'Broad Vein' or 'Broad Slate-Bed', and he cites Abercwmeiddaw as a quarry in the 'Broad Vein'. The 'Broad Vein', according to his section, is overlain by the 'Black Rock'.

[1] Q. J. G. S. vol. viii (1852) p. 148.
[2] *Ibid.* vol. ix (1853) p. 163.
[3] Geological Survey of Great Britain, 1-inch Sheet, Old Series, 59, N.E.
[4] 'Records of the Rocks' 1872, p. 104.

There is little doubt that the succession given by Davies should be reversed, and that the 'Narrow Vein' overlies the 'Broad Vein', which in its turn overlies the 'Black Rock'. This reading is corroborated by the fossils which have now been obtained from the different groups.

In addition, Davies gives a list of quarries in the Corris area, stating the particular slate-bed in which each quarry is located, and this, in many cases, requires modification.

In 1881, Sir Andrew Ramsay [1] described the 'Bala Beds, south of Cader Idris' in some detail. He stated that no fossils had been discovered between Aberdovey and the Bala Limestone beyond Dinas Mawddwy. He considered that the sandy beds of Garnedd-wen might be 'on the general parallel of the Bala Limestone, or of the fossiliferous strata not far below' (*op. cit.* p. 106). This latter statement is improbable, for the sandy beds of Garnedd-wen are part of the highest Ordovician group in the Corris area.

In the same year, Walter Keeping [2] described the occurrence of graptolites in this area, and, so far as I am aware, that is the first and only record of fossils. Up to that time the area had been considered by all investigators as entirely devoid of fossils. Keeping referred the Corris rocks to his 'Metalliferous Slate Group', and recorded from Corris and Taren y Gesail *Monograptus sedgwickii (?)* Portlock, *M. tenuis (?)* Portlock, *Climacograptus scalaris* Hisinger, and *Orthoceras* sp. The graptolites were, in all probability, obtained from the now disused slate-quarries in the Birkhill rocks at Corris and Taren y Gesail.

After Keeping's paper, the only other reference to the area is that by Prof. W. G. Fearnsides in 1910.[3] He states that a monotonous series of dark banded mudstones overlies the Llandeilian volcanoes along the southern flanks of Cader Idris and the Arans, and that they probably, therefore, represent some part of the Caradocian.

Prof. A. H. Cox and Mr. A. K. Wells have been working for some years in the adjoining area around Dolgelly and the main Cader Idris range. The details of their investigations, concerning the lower part of the Ordovician succession, have recently been published,[4] and a summary of the general Ordovician succession up to the highest volcanic rocks is contained in a Report to the British Association.[5]

The present paper describes the succession of the Upper Ordovician and Lower Silurian rocks lying south-east of the Cader Idris area, and is intended, in some measure, to bridge over the gap in our knowledge concerning the rocks and structure of the country lying between Cader Idris and Machynlleth, the geology of the latter place having been described in 1915.[6]

1 'The Geology of North Wales' Mem. Geol. Surv. 2nd ed. (1881) p. 105.
2 Q. J. G. S. vol. xxxvii (1881) p. 162.
3 Jubilee Vol. Geol. Assoc. 1910, pp. 799, 804, 816.
4 A. H. Cox & A. K. Wells, Q. J. G. S. vol. lxxvi (1920–21) p. 254.
5 A. H. Cox & A. K. Wells, Rep. Brit. Assoc. (Manchester) 1915, p. 424.
6 O. T. Jones & W. J. Pugh, Q. J. G. S. vol. lxxi (1915–16) p. 343.

III. General Succession and Structure.

The rocks of the Corris-Aberllefenni area belong to the Upper Ordovician and Lower Silurian. They consist of mudstones, slaty shales, and slates, with subordinate bands of grit. The arenaceous beds are largely confined to the highest Ordovician and the highest Silurian rocks examined. The Ordovician grits pass laterally, in some places, into strong quartzose conglomerates.

Synopsis of the Succession.

Valentian.	Ystwyth Stage.		Pale mudstones, with numerous laminated grit-bands.
	Pont Erwyd Stage.	Derwen Group.	Pale greyish-blue mudstones, with dark graptolitic shale-bands.
		Cwmere Group.	Blue and dark-blue shales and mudstones, with thin siliceous seams and a pronounced rusty weathering. Base of the group defined by the zone of *Glyptograptus persculptus* or 'Mottled Beds', consisting of thinly bedded mudstones.
Bala.		Abercorris Group.	3. Garnedd-wen Beds. Mudstones, with bands of grit. Gritty mudstones and some conglomerates. 2. Narrow Vein (=Y Faen gul). Dark-blue slate. 1. Red Vein (=Y Faen goch). Dark-blue mudstones, in parts mottled with dark patches. Zone of *Dicellograptus anceps*.
		Abercwmeiddaw Group.	Broad Vein (=Y Faen lydan). Bluish-grey mudstones, characteristically mottled, locally greyish-blue slates developed. *Trinucleus*, *Cyclopyge*, etc.
		Hengae Group.	2. Nod Glas. Coal-black shales and blocky mudstones, pyritous. *Dicranograptus clingani*, *Dicellograptus morrisi*, and *Dicellograptus forchammeri*, etc. 1. Ceiswyn Beds. Greyish-blue slaty mudstones, with thin gritty bands. In the lower part are highly cleaved dark slates.
Llandeilo.		Craig y Llam Group.	Rhyolitic lavas and ashes. (The Upper Acid or Craig y Llam Series of A. H. Cox & A. K. Wells.)

The development of the Silurian rocks is very similar to that described in the Machynlleth[1] area, both in lithology and in fauna. It is proposed, therefore, to adopt the same nomenclature and subdivisions as those given at Machynlleth, in order to avoid so far as possible the confusion of new local names. Further, it is not intended to describe the Valentian rocks in detail, but rather

[1] O. T. Jones & W. J. Pugh, Q. J. G. S. vol. lxxi (1915–16) p. 343.

to give some account of the Upper Ordovician rocks, concerning which, in this area, we have so far comparatively little information.

Most of the important slate that is quarried in this area occurs in the Ordovician: accordingly, to various parts of the Upper Ordovician local names have been applied, and it is proposed in this paper to retain those names so far as possible.

The area may be regarded as constituting part of the south-eastern flank of the Harlech Dome. The beds strike approximately from south-west to north-east, and dip steeply south-eastwards.

The area is traversed by a series of anticlines and synclines, the axes of which are transverse to the general direction of strike, and trend approximately north-north-east and south-south-west, in some places, indeed, practically north and south. A conspicuous southward pitch is noted throughout the region described.

There is comparatively little faulting, except in the neighbourhood of the great Tal-y-llyn or Bala Fault. Here the mapping of the upper margin of the volcanic rocks has revealed several faults ranging approximately parallel to the Tal-y-llyn Fault. The northern part of the area is affected by transverse faults of comparatively small effect, which trend north-west and south-east, and apparently die out south-eastwards. Southwards the only important fault is that which runs parallel to the strike at Aberllefenni.

The rocks of the area are affected by a powerful cleavage, which is approximately parallel to the strike of the beds. Generally, the cleavage is vertical or very steeply inclined south-eastwards; but the inclination of the cleavage-planes diminishes somewhat as the margin of the volcanic rocks is approached, though it is still as much as 60° to the south-east. The diminution in the inclination of the cleavage-planes is generally accompanied by a diminution in the dip of the beds.

IV. Detailed Description of the Beds.

Llandeilo.

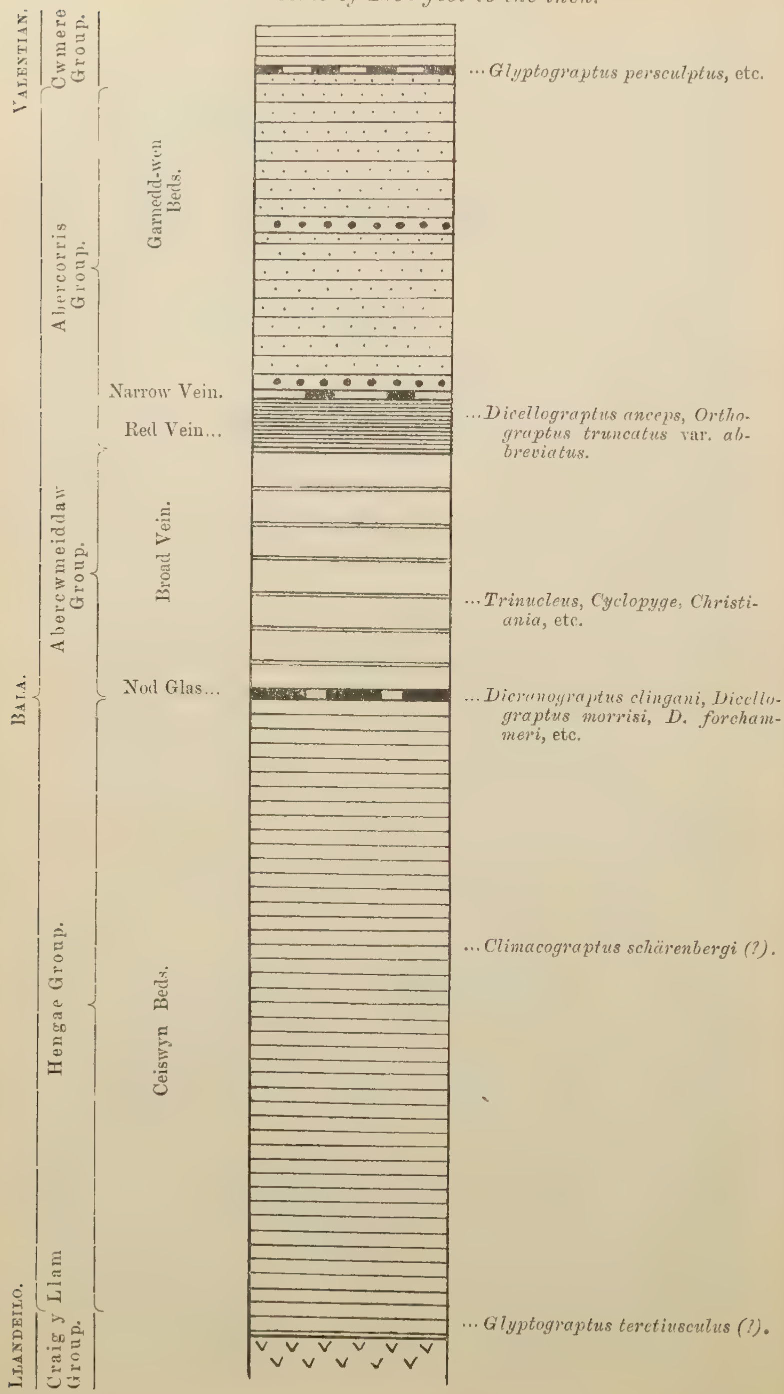
Craig y Llam Group.—The highest volcanic rocks of the Ordovician in this area are particularly well exposed in the great bluff on the south side of the Tal-y-llyn Valley called Craig y Llam, and also on the north-western slopes of Mynydd y Waun and Mynydd Ceiswyn. They have been called by Prof. A. H. Cox & Mr. A. K. Wells 'the Upper Acid Craig y Llam Series.' They consist of rhyolitic ashes and lavas, which weather to a greyish-white.

For the purpose of this paper, I have only examined the volcanic rocks immediately underlying the Ceiswyn Beds; but it is stated that the group as a whole is about 900 to 1000 feet thick.[1]

The boundary between the volcanic rocks and the overlying sedimentary rocks is sharp and abrupt, and can be mapped accurately. The junction is well exposed in several localities: as, for

[1] A. H. Cox & A. K. Wells, Rep. Brit. Assoc. (Manchester) 1915, p. 424.

Fig. 1.—*Vertical section through the Ordovician rocks, on the scale of 1200 feet to the inch.*



instance, at the head of the Llefenni Valley (north of Waun Llefenni), along Nant y Benglog on Craig y Llam, and in several places on the north-western slopes of Mynydd Ceiswyn.

At the head of the Llefenni Valley is a continuous section in the stream, from the volcanic rocks into the Ceiswyn Beds. There the highest volcanic rocks consist of well-bedded rhyolitic ashes which are overlain by dark-blue slaty mudstones. There are one or two thin bands of ashy mudstone a few feet above the main mass of the volcanic rocks: but these do not seem to be present in all sections which have been examined. Near the junction a good deal of vein-quartz occurs commonly, and in the Llefenni section this appears to contain traces of lead. Vein-quartz containing lead is known to occur at this horizon in several other localities outside the area described in this paper, as, for example, north and north-west of Dinas Mawddwy.

It may be mentioned that the Mynydd y Waun outcrop lies on the axis of a well-marked anticlinal structure which passes west of Corris, and has been traced for some distance south of that village into the Machynlleth area.

Bala.

Hengae Group.

(1) Ceiswyn Beds.—Immediately overlying the highest Ordovician volcanic rocks is a great group of monotonous slaty mudstones, generally dark blue and greyish blue. It is a thick group which occupies a considerable portion of the area described in this paper.

The lower part consists of very dark-blue, highly cleaved slates. These dark slates are not homogeneous in character, but are traversed by fine-grained gritty bands up to an inch or more in thickness. They have at various times been quarried for roofing-slates, but none of the quarries are at present working: for instance, the old quarries at the head of the Llefenni Valley and on Mynydd y Waun.

These dark slates possess characteristic physical properties which distinguish them from all other slates in the area. They are highly cleaved, and split readily into thin sheets. Fresh cleavage-planes possess a silky lustre. Their economic value is somewhat diminished by the presence of numerous small joints, the thin gritty bands mentioned above, pyrite-cubes which are often numerous along the bedding-planes, and the presence in some localities of a characteristic wavy cleavage.

I have searched these slates on several occasions for fossils; but, so far, they have only yielded very imperfectly preserved traces of graptolites. One of these may possibly be *Glyptograptus teretiusculus*; the others are of the Diplograptid type, and are not capable of identification. The slates are so highly cleaved that they are difficult to split along the bedding-planes. However, there is little doubt that they do contain graptolites and also forms

capable of identification, for some years ago I saw sample slates from this group, obtained from one of the quarries at the head of the Llefenni Valley, which had fairly well-preserved graptolites on their edges. At that time, however, I had no facilities for examining them in detail, and although subsequently, on various occasions, I have searched the actual quarry from which they were obtained, I have been unable to find the graptolite-bearing band.

Prof. Cox & Mr. Wells (Rep. Brit. Assoc. 1915, p. 425) record farther west *Amplexograptus arctus* and *Glyptograptus teretiusculus* var. *euglyphus* from the lowest beds of their Tal-y-llyn Mudstones, and I have little doubt that these fossils occur on much the same horizon as the slaty beds described above. They state, therefore, that these forms indicate '. . . . a high horizon in the Glenkiln or, in other words, a low horizon in the Caradocian.'

This dark slaty series is succeeded by the main mass of the Ceiswyn Beds. The cleavage in the higher beds is not generally so conspicuously developed as in the lower, nor are the beds so dark. They are greyish-blue slaty mudstones, with gritty bands up to an inch or more in thickness. Some parts of the group present a banded appearance, owing to alternation of paler and darker mudstones. Pyrite-cubes occur commonly along the bedding-planes. The greater part of the group possesses a pale yellowish-brown weathering, except the highest beds underlying the Nod Glas, which commonly show a well-marked rusty-brown weathering. It may be mentioned incidentally that some parts of the Ceiswyn Beds have lithological characters similar to parts of the Upper Valentian or Tarannon rocks of Central Wales.

It appears impossible to separate this group of mudstones into subdivisions that are capable of being mapped with any degree of accuracy. The slight lithological differences which characterize different parts of the Ceiswyn Beds merge one into the other so insensibly that they afford little or no assistance in surveying. The dark slaty group at the base might be mapped in a general way; but its upper limit is very indefinite.

The Ceiswyn Beds are well exposed throughout the area; but two sections, in particular, may be mentioned as affording good continuous exposures—the Llefenni Valley from Cambergi to the junction with the volcanic rocks, and the line of crags on Ffridd Newydd, on the west side of the Ceiswyn Valley, in which all the beds from the black graptolitic shales of the Nod Glas to nearly the base of the group are well exposed.

I have several times worked through stream and other sections in this group, but have so far failed to find any fossils, except some imperfectly-preserved graptolites at one point in the Ffridd Newydd Crags. From the latter spot, I have obtained badly-preserved specimens, all of which may probably be referred to the species *Climacograptus schärenbergi* Lapworth. These graptolites occur about 1500 feet below the Nod Glas, in rather dark shales with rusty weathering tints.

The Ceiswyn Beds as a whole look unpromising from the point

of view of fossils, and, if graptolites do occur in any abundance, it appears probable that they are confined to thin bands which, so far, I have been unable to find.

The total thickness of the beds is estimated to be nearly 4000 feet, and the dark slaty group at the base about 200 feet. The group is somewhat thinner than might be expected from the area which it covers, owing to a certain amount of minor folding and rolling, so that beds on the same horizon may be repeated in any given section.

(2) Nod Glas.—The monotonous slaty mudstones of the Ceiswyn Beds are succeeded at once by coal-black shales and mudstones. In some localities they are very highly-cleaved papery shales, in others they possess a tough, blocky mudstone character. These black shales are traversed by numerous joint-planes. They weather to a pronounced rusty colour, and are strongly pyritous.

It is a well-known band among local quarrymen, because of its highly characteristic lithological characters, and because it marks the lower limit of the slate-bearing rocks which are commonly worked in this country. It is called by them the Nod Glas (=Blue Mark).

This black shale-band, which is about 70 feet thick, makes a very characteristic hollow between the harder Ceiswyn Beds and the mottled Abercwmeiddaw Mudstones above. This hollow is well marked throughout the area, and enables one to trace the position of the band, where it is not exposed, without difficulty (see fig. 2, p. 522).

Because of its comparatively soft character, it is not commonly well exposed, except in occasional stream-sections. The beds of such streams flowing over the Nod Glas are often stained a reddish brown, and large blocks of breccia may be found in the streams, consisting of weathered fragments of the black shale, cemented into a hard mass by ferruginous material.

The two best exposures in the area are (1) in the small stream immediately west of Ratgoed Chapel, in the Ceiswyn Valley and called locally Nant yr aur, although this name is not recorded on any of the Ordnance Survey maps; (2) on the south-west side of Craig Hengae, where a small unnamed stream cascades down the steep valley-slope into the river Llefenni. In both cases the small streams flow for some distance along the outcrop of the Nod Glas, and the band is fairly well exposed. There are also several smaller exposures: for instance, in Nant Cwmeiddaw, north of Corris.

In several localities there appears to be evidence of movement along this shale-band, resulting in the shattering of the rock, etc. North-west of Corris the outcrop of the overlying Abercwmeiddaw Mudstones is comparatively narrow, and this may be due to strike-faulting along the general line of the Nod Glas. If such a strike-fault does exist, it may possibly be the continuation of the Aberllefenni strike-fault, which has been proved on the north-east.

This black shale-band is very fossiliferous, and graptolites are

extremely abundant, some of the bedding-planes being covered with *Dicellograpti* and *Climacograpti*. These graptolites are, however, commonly distorted, and not very well preserved. It is a curious fact that such a characteristic band should have escaped the attention of earlier investigators in the area.

Graptolites are most easily obtained from the Nant yr aur and Craig Hengae exposures. From the former I have collected fairly well-preserved specimens of:—

Dicellograptus forchammeri Geinitz.
Dicellograptus morrisi Hopkinson.
Dicranograptus clingani Carruthers.
Climacograptus minimus (Carruthers).
Climacograptus scalaris var. *miserabilis* Elles & Wood.
Climacograptus styloideus Lapworth.
Climacograptus tubuliferus Lapworth.
Orthograptus calcaratus var. *basilicus* Lapworth.
Orthograptus truncatus var. *socialis* Lapworth.
Orthograptus sp.
Glyptograptus (?).

Mr. G. J. Williams informs me that he has found *Plegmatograptus nebula* Elles & Wood in this locality.

From Craig Hengae I have obtained :—

Dicranograptus clingani Carruthers.
Dicranograptus cf. *clingani* Carruthers.
Climacograptus styloideus Lapworth.
Orthograptus cf. *quadrimucronatus* Hall.

In addition to these graptolites, I have collected from exposures a short distance north-east of the area at present described *Orthograptus quadrimucronatus* (Hall) and *O. truncatus* var. *pauperatus* Elles & Wood.

The most abundant graptolites are the *Dicellograpti* and the *Climacograpti*, particularly *Climacograptus minimus*. Specimens of *Dicranograptus* are relatively rare, and, although they belong in all probability to the species *D. clingani*, they are small and dwarfed forms.

The general aspect of the fauna seems to indicate that of the zone of *Dicranograptus clingani*; but there are several forms which suggest also the higher horizon of *Pleurograptus linearis*. The specimens of *Dicellograptus* appear to occur most abundantly towards the top of the black shales. At a slightly lower horizon the bedding-planes may be crowded with *Climacograpti*: for instance, *Climacograptus minimus*; while the black shales which contain *Dicranograptus* are probably at a somewhat lower horizon still. It is possible that there are different levels within this black shale-band, which may be characterized by somewhat different assemblages of graptolites, although, so far, I have not been able to investigate this in detail. The rocks are highly cleaved, and, in many cases, it is difficult to extract recognizable forms.

It is possible, therefore, that the Nod Glas may actually represent the junction between the zones of *Dicranograptus clingani* and *Pleurograptus linearis*, or indeed that the very highest layers of the black shale may belong to the latter zone.

Abercwmeiddaw Group.

The Nod Glas is succeeded at once by a group of mudstones possessing very characteristic lithological and faunal features. They consist of pale greyish-blue, thickly bedded mudstones, rather paler than any of the other Upper Ordovician rocks in this area. They are especially characterized by a coarse mottling, consisting of large dark patches which measure as much as an inch in diameter, and are irregular in outline. At some horizons, particularly in the lower part of the group, calcareous nodules are fairly abundant, and the group as a whole appears to become rather more calcareous as it is traced along its outcrop from south-west to north-east.

Locally, parts of the group lose the mottled character, and pass into well-cleaved greyish-blue slates. These somewhat irregular slate-bands, which are commonest in the lower part of the group, have been worked in several places for slates and slabs: as, for instance, at the Abercwmeiddaw and Cambergi Quarries. They cleave well, and often make good roofing-slates or may be sawn into large slabs. These slates may readily be distinguished from the other slates quarried in the area by their comparatively light grey colour and their texture. The slate in this group is called the Broad Vein (Y Faen lydan) by the local quarrymen, although the slate quarried is not everywhere on exactly the same horizon.

This group of mudstones, which weathers brown, is well exposed throughout the area, and generally gives rise to somewhat rough, craggy ground. In some places there are large quarries, particularly in the lower part of the group: as, for instance, the Abercwmeiddaw and Cambergi Quarries already mentioned. In addition, there are numerous smaller trial-quarries: for example, Cwm-dylluan Quarry, and on the south side of the Ceiswyn valley, etc.

The Abercwmeiddaw Group contains only shelly fossils, so far as I am aware; but they are somewhat rare in the Corris-Aberllefenni area. It is difficult to extract recognizable fossils from the rocks *in situ*, because the mudstones are tough and split with difficulty along the bedding-planes. In addition, the fossils are scarcely distinguishable on freshly broken pieces, possessing (as they do) the same general colour as the matrix in which they are preserved. On weathered fragments and in the tips from the quarries in the group, on the other hand, fossils are more readily distinguished, and weather to a conspicuous brown colour.

There is little doubt that the group, as a whole, is more fossiliferous in the lower part. At the same time, it should be remembered that most of the quarries and trial-workings are situated in the lower part, and it is from these only that I have been able to obtain fossils. The upper part is well exposed in numerous crag- and stream-sections; but it has not yielded any fossils capable of identification.

The most important locality for fossils is the Abercwmeiddaw Quarry, where the following forms have been obtained:—

Christiania tenuicincta (M'Coy).	*Cyclopyge (?)* sp. (eyes).
Orthis sp.	*Harpes* sp.
Plectambonites sericea, cf. var. *albida* Reed.	*Trinucleus albidus* Reed.
Cyclopyge rediviva (Barrande).	*Trinucleus* cf. *albidus* Reed.
Cyclopyge armata (Barrande).	*Trinucleus* sp.

The Abercwmeiddaw Quarry is about 400 feet above the Nod Glas.

From the Cambergi Quarry the following have been collected:—

Brachiopod indeterminate (? *Zygospira*).	*Cyclopyge subarmata* Reed.
Large Asaphid.	*Harpes* sp.
	Trinucleus cf. *concentricus* Eaton.

The Cambergi Quarry is about 200 to 250 feet above the Nod Glas.

From an old trial-level on the south side of the Ceiswyn Valley, about 300 to 400 feet above the Nod Glas, the following have been obtained:—

Asaphid sp. (? *A. radiatus*).	*Trinucleus* cf. *concentricus* Eaton.
Cyclopyge (?) sp. (eye).	*Trinucleus albidus* Reed.
Harpes sp.	*Trinucleus* sp.

From the mudstones on the north side of the Llefenni Valley, I have obtained a large Asaphid, *Christiania tenuicincta* (M'Coy), crinoid-stems, and a fragment of an indeterminate trilobite. The horizon of these fossils is more difficult to determine, but it lies at a maximum of probably not more than 600 feet above the Nod Glas.

The most abundant specimens are those of *Trinucleus*; in many cases, however, it is impossible to make a specific identification, owing to the fragmentary nature of the material. Trilobite-eyes belonging probably to species of *Cyclopyge* are also fairly common; but the main interest of the fauna lies in the discovery of no less than three species of *Cyclopyge*. The fauna recalls at once that of the *Dionide* Band in the Upper Whitehouse Group at Girvan,[1] where the band is associated with the graptolite-shales of the *Dicellograptus-complanatus* Zone.

The Abercwmeiddaw Mudstones are about 1500 feet thick.

Abercorris Group.

(1) Red Vein.—The mottled mudstones of the Abercwmeiddaw Group are succeeded by a group of mudstones about 350 feet thick, with a well-marked rusty weathering. These mudstones are tough, dark-blue, and blocky; when highly cleaved and well weathered, they are often difficult to distinguish lithologically from the Cwmere Group or Lower Birkhill rocks of this area.

[1] C. Lapworth, Q. J. G. S. vol. xxxviii (1882) p. 598.

There are two bands within these rusty-weathering mudstones which are somewhat harder than the rest of the Red Vein, and they often stand out, making well-marked features: as, for example, where the Red Vein crosses Foel Crochan, north of Aberllefenni (see fig. 2, p. 522). These harder bands are generally mottled, like the Abercwmeiddaw Mudstones which underlie them.

The mudstones are called the Red Vein (Y Faen goch) by the local quarrymen, because of their rusty-red weathering. They are well exposed in a number of places, and may be examined in detail at the Abercorris, Aberllefenni, and Ratgoed Quarries, as also in the Ceiswyn stream, etc.

At the Abercorris Quarries they yield abundantly, about the middle of the group, *Orthograptus truncatus* var. *abbreviatus* Elles & Wood and *Climacograptus scalaris* var. *miserabilis* E. & W. The same forms may be collected in the Ratgoed Quarries, at approximately the same horizon.

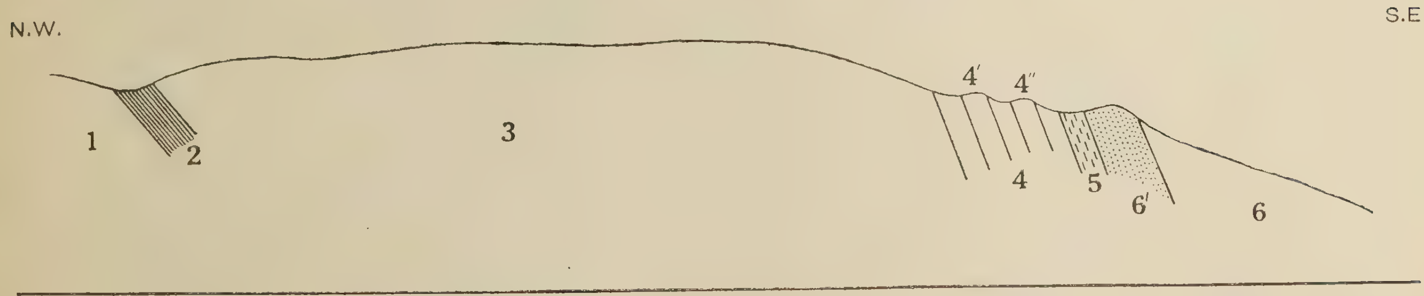
The Red Vein is also well exposed in the Ceiswyn stream, and here I have collected several specimens of *Dicellograptus anceps* Nicholson and *Climacograptus scalaris* var. *miserabilis*. This band with *Dicellograptus anceps* is, I believe, at a slightly higher horizon than that which yields *Orthograptus truncatus* var. *abbreviatus* in such abundance at the Abercorris Quarries and elsewhere.

The most abundant graptolite is *Orthograptus truncatus* var. *abbreviatus*. It is generally very well preserved in full relief, and is extremely abundant in most localities where these beds are exposed. Specimens of *Dicellograptus anceps* are comparatively rare, and may be confined possibly to a narrow shale-band within the group. This clearly corresponds to the Zone of *Dicellograptus anceps*.

(2) Narrow Vein.—The Red Vein is succeeded by a comparatively thin bed of dark-blue homogeneous mudstone, which is locally called the Narrow Vein (Y Faen gul). This band of mudstone is well cleaved, and constitutes the most important slate-bed in the Corris area. It is practically a pure, clean slate, remarkably free from pyrites, etc.

The outcrop of this slate-bed is not difficult to follow over the greater part of the area, on account of the numerous quarries which are located on it. Beginning in the south-west, it is exposed almost continuously from the Ty'n-y-berth Quarries, through Ty'n-y-ceunant Quarry into the Braich-goch Quarries, and thence into the Gaewern Quarries, across the Afen Deri to the Abercorris Quarries. From the last-named point, the band trends in a general north-easterly direction across Mynydd Abercorris and Godre Fynydd, until it is again well exposed in the Aberllefenni Quarries on both sides of the Llefenni Valley. Thence it crosses over Foel Crochan, and is exposed once more in the Cymerau and Ratgoed Quarries in the north-eastern part of the area described.

Fig. 2.—*Diagrammatic section along Foel Crochan, north of Aberllefenni, illustrating the characteristic features of the outcrops of the Upper Ordovician rocks.*



1 = Ceiswyn Beds (greyish-blue slaty mudstones, with sandy seams). 2 = Nod Glas (soft black shales).
3 = Abercwmeiddaw Beds (greyish-blue mudstones, coarse mottling).
4 = Red Vein (rusty-weathering shales, with harder mottled mudstones in bands 4′ & 4″).
5 = Narrow Vein (dark-blue slate-band). 6 = Garnedd-wen Beds (gritty mudstones, with prominent grit-band 6′).

The upper and lower limits of this slate-band (or, as the quarrymen term them, the 'top slip' and 'bottom slip') are, in nearly every case, very well defined. The lower limit is clearly marked off by its contact with the somewhat rubbly, rusty-weathering mudstones of the Red Vein; while the top of the slate-band ends off abruptly against the grits and gritty mudstones of the Garnedd-wen Beds. At Aberllefenni particularly, the slate-band terminates against a massive grit-band quite abruptly. The slate is stripped off this grit-band, and the latter then constitutes a good 'roof' in underground workings. North-east of Aberllefenni Quarries (for instance, at Ratgoed, where the slate-band is overlain by mudstones), the upper limit is perhaps not capable of such precise definition as farther south; but, even then, there is a well-marked lithological change within a few feet. However, in practically all the quarries, the full width of the slate has been worked, and the band is correspondingly well exposed.

There seems to be little doubt that the physical characters of the Narrow Vein vary from point to point and within comparatively short distances, although such changes cannot be observed in hand-specimens. These changes have important effects upon the economic value of the slates and slabs obtained from it. One of the chief difficulties against which quarry-owners have to contend, is the tendency for slabs to 'pillar'—that is, to split at right angles to the cleavage and in directions opposed to the jointing. Slabs from some quarries, even in this comparatively narrow slate-band, appear to 'pillar' more readily than those obtained from others, even when the quarries are separated by quite a short distance. In fact, I believe, slabs obtained from different parts of the same quarry have somewhat different physical properties. The tendency to 'pillar' is especially noticeable when the slabs are exposed to the atmosphere for some time, or experience sudden changes of temperature. The exact cause of 'pillaring,' etc. is, so far as I am aware, at present imperfectly understood.

In addition to roofing-slates, the Narrow Vein yields large slabs of excellent quality, which are marketed for a variety of purposes: as, for example, billiard-tables, brewing-vats, electric switch-boards, etc.

The band is about 50 to 60 feet thick, sometimes rather less than that amount: for instance, in the Gaewern Quarry.

I have not obtained any fossils from the Narrow Vein, but Mr. G. J. Williams has collected *Orthoceras perannulatum* from the Braich-goch Quarries and *Phacops* sp. from the Cymerau Quarries.

(3) Garnedd-wen Beds.—These beds succeed the Narrow Vein conformably; they consist of dark-blue micaceous mudstones, often sandy or gritty, and contain subordinate bands of massive grit.

The mudstones possess very marked lithological characters, and may readily be distinguished from all other sedimentary types

in the area. They weather to a dull bronze in most exposures. They are very imperfectly cleaved, and appear to possess a rough double cleavage which causes them to split into lenticular or phacoidal pieces with rather sharp edges. Within a very short distance they may become quite arenaceous, and develop definite grit-bands. In other places they contain large isolated masses of grit and gritty mudstone, which are boulder-like in shape, and give to the rock a peculiar gnarled or 'pillowy' appearance.

At certain horizons well-marked grit-bands are developed, which are capable of being mapped. The grit-bands may, however, quite suddenly pass into gritty mudstones, which are indistinguishable from the group as a whole. Further, there is reason to believe that these thick grit-bands do not in all cases maintain a constant stratigraphical position; and, on account of this, together with their variation in thickness and lateral change, it is doubtful whether any useful purpose would be served by mapping them in detail. In certain places, however, they assist in the elucidation of the geological structure.

Another somewhat remarkable characteristic of these grit-bands is worthy of mention. Not only may they pass quite suddenly into gritty mudstones, indistinguishable from the group as a whole, but they may within a few feet pass into massive conglomerates. These conglomeratic bands are quite local in their distribution, and are particularly well shown on Mynydd Abercorris, as also on the south side of the Llefenni Valley. They are several feet thick, and consist of well-rounded pebbles in a mudstone or gritty mudstone matrix. The pebbles may be as much as 5 to 6 inches in diameter, and are composed mainly of vein-quartz, with occasional gritty and quartzitic pebbles. These quartzose conglomerates crop out in irregular patches about the middle of the Garnedd-wen Beds.

Generally speaking, there are two fairly well-marked grit-horizons: one about the middle of the group (for instance, south of Corris, about 1000 feet below the base of the Valentian); and one a little distance above, or immediately above, the Narrow Vein.

The grits may be examined practically anywhere on the outcrop of the group; but two typical localities may be cited:—

(1) South of Corris on Mynydd Braich-goch and Bryn Llwyd, a thick grit-band occurs about the middle of the Garnedd-wen Beds. Owing to its superior hardness, it makes a well-marked feature, and its outcrop may be traced for a considerable distance. It consists of a hard quartzose grit, and immediately south of Corris the outcrop makes a sharp V as it crosses the axis of the Corris Anticline. In several places the grit-band is veined with quartz in all directions.

(2) On Foel Crochan, north of Aberllefenni, the Narrow Vein is overlain by a massive grit-band about 100 feet thick, which makes a conspicuous feature as it crosses over the ridge from the Llefenni Valley into the Ceiswyn Valley.

One of the most remarkable features of the Garnedd-wen Beds

is their attenuation as they are traced from south-west to north-east. In the south-west, on the margin of the area described, they are about 2000 feet thick. At Corris itself they are probably about 1800 feet, and immediately north of Garnedd-wen Station about 1400 to 1500 feet thick. North-east of Aberllefenni the diminution in thickness is very marked. At Cymerau they are about 650 feet thick, while on the extreme eastern margin of the area described they are not more than 500 feet thick. The Garnedd-wen Beds, therefore, diminish in thickness from about 2000 to 500 feet in a distance of little more than 6 miles along the strike.

This diminution in thickness is accompanied by a loss of arenaceous material. In the eastern part of the area, from Cymerau to Ratgoed, the Garnedd-wen Beds are almost exclusively a mudstone group with no conspicuous grit-bands. A particularly good example of this loss of arenaceous material is seen in the Ceiswyn Valley. From Aberllefenni over Foel Crochan, the Narrow Vein is overlain by the conspicuous massive grit already mentioned. This grit-band is maintained on the north side of Foel Crochan; but, almost immediately after crossing the Ceiswyn stream, it dies out quite suddenly, and the Narrow Vein is overlain by a very characteristic group of dark-blue mudstones, weathering to a pale brown. These mudstones are traversed by thin irregular seams of greyish siliceous material. These siliceous seams have a distinct current-bedded appearance, and a characteristic contorted or 'curled' bedding. Weathered fragments give concentric weathering tints. These mudstones with siliceous seams overlying the Narrow Vein are well known to the local quarrymen, by whom they are appropriately called the 'ribbony rock'.

The mudstones, gritty mudstones, grits, and conglomeratic bands of the Garnedd-wen Beds in the Corris-Aberllefenni area are precisely similar to the Ordovician rocks which crop out in the crests of anticlines and occupy such considerable areas in the northern part of Central Wales.[1]

No fossils have been found in these beds in the Corris-Aberllefenni area; but north-eastwards in the Dinas Mawddwy country, I have collected specimens of *Phacops mucronatus* from the lowest beds of the Garnedd-wen mudstones, immediately overlying the Narrow Vein.

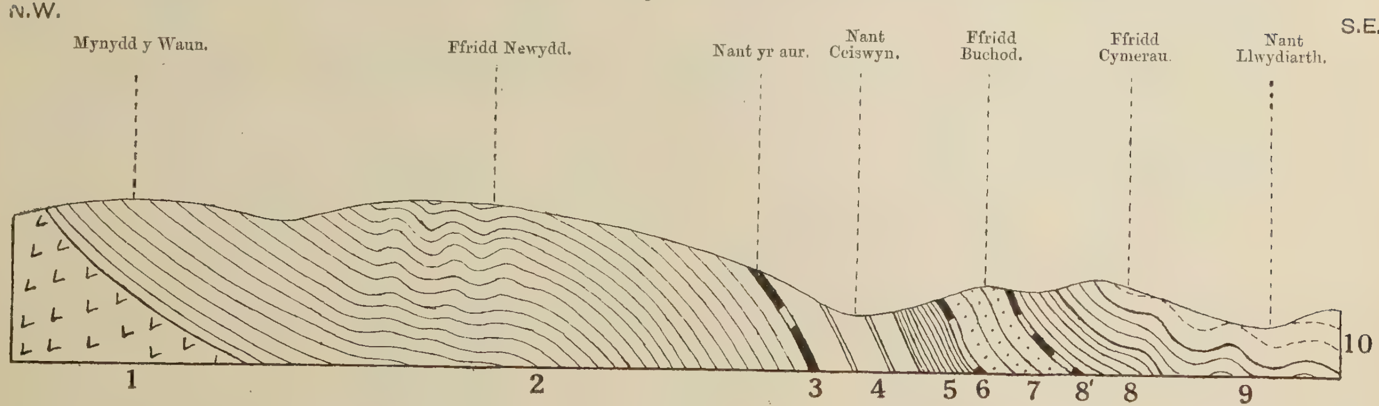
Valentian.

Pont Erwyd Stage.

Cwmere Group.—As at Machynlleth, this group consists of dark-blue shales, with subordinate siliceous bands and an occasional band of grit. The group is especially characterized by its pronounced rusty weathering, which serves to distinguish it from

[1] O. T. Jones & W. J. Pugh, Q. J. G. S. vol. lxxi (1915–16) p. 347; O. T. Jones, *ibid.* vol. lxv (1909) p. 468; and *id.* Special Reports on the Mineral Resources of Great Britain: vol. xx Lead & Zinc, Mem. Geol. Surv. 1922.

Fig. 3.—*General section from Mynydd y Waun to Nant Llwydiarth, showing the relations of the rock-groups, on the scale of 3 inches to the mile.*



1=Craig y Llam volcanic group. 2=Ceiswyn Beds. 3=Nod Glas. 4=Abercwmeiddaw Group. 5=Red Vein. 6=Narrow Vein. 7=Garnedd-wen Beds. 8=Cwmere Group (with 8′, zone of *Glyptograptus persculptus*). 9=Derwen Group. 10=Ystwyth Stage.

all other rocks in the area, except possibly the Red Vein of the Upper Ordovician. From the latter, it may be distinguished lithologically by its more shaly character, rather more pronounced rusty weathering, and absence of a coarse mottling which occurs in parts of the Red Vein. In the Corris area the rocks of the Cwmere Group are very highly cleaved, and graptolites are extremely difficult to extract in a state capable of identification.

The base of the Cwmere Group is marked by the zone of *Glyptograptus persculptus*, or, as it has been called, the 'Mottled Beds'. This zone maintains all the characters which have been described in the area farther south, and the band has been, in the Corris-Aberllefenni area, as throughout much of Central Wales, a valuable guide in deciphering the geological structure. For that reason, it has been mapped right through from Machynlleth into the Corris area, and for some miles north-east and east of the area at present described.

The zone consists of compact dark-blue mudstones, in which paler bands occur. These paler bands are characterized by a small irregular mottling. It has already been observed that the Abercwmeiddaw Mudstones and part of the Red Vein are mottled; but the character of the mottling is quite different, and there is no difficulty in distinguishing even small hand-specimens. The mottling in the case of the Ordovician rocks is much coarser, the blotches are much larger, and they are not confined to paler bands within a dark mudstone group. The actual character of the mudstone and the weathering tints are distinct in each case.

Throughout the area, the zone of *Glyptograptus persculptus* rests with apparent conformity on the Garnedd-wen Beds. There is an abrupt change in lithology at the junction, and it is this lithological change which makes the zone so valuable from the point of view of surveying.

In describing the Machynlleth area, Prof. O. T. Jones and I made the following statement:—

'It is significant also that, in contrast with the constancy of character which distinguishes the Mottled Beds, the strata upon which they rest exhibit considerable variation from locality to locality. In the absence of fossiliferous horizons, it is not possible to decide whether this is due to the variability of the underlying group, or to an overstep of the Mottled Beds on to different horizons of the older beds' (Q. J. G. S. vol. lxxi, 1915–16, p. 351).

Since that statement was made, the Mottled Beds, together with the next underlying fossiliferous horizon: namely, the Red Vein, with *Dicellograptus anceps* and *Orthograptus truncatus* var. *abbreviatus*, have been mapped over a considerable part of the area from Machynlleth through Corris to Dinas Mawddwy, a distance of some 15 to 16 miles. The top of the Red Vein passes into the Narrow Vein, which is another datum-line capable of accurate mapping, and has been traced continuously from west of Corris to Dinas Mawddwy.

The strata upon which the Mottled Beds rest do undoubtedly exhibit variation from locality to locality; but the Mottled Beds do not overstep on to different horizons of the older beds. The

variability in the character of the strata immediately underlying the Mottled Beds is considered to be due to actual lithological variation within the underlying group, evidence of which has already been given when describing the Garnedd-wen Beds. The latter thin out so rapidly from south-west to north-east in the Corris area, that it might be supposed that still farther away to the north-east the Mottled Beds might actually overstep on to the beds with *Dicellograptus anceps*. An examination of a somewhat larger area than that at present described lends no support to the supposition; on the contrary, the diminution in thickness is due to a loss of arenaceous material as the Garnedd-wen Beds are traced north-eastwards and eastwards.

It is considered, therefore, that in the Corris area the Mottled Beds lie conformably on the Ordovician rocks; but there is an abrupt change in the lithological characters, which indicates some distinct change of physical conditions preceding the formation of the Mottled Beds.

These beds are well exposed in a number of places: as, for example, in the old quarries at Taren y Gesail, where practically the whole thickness of the zone is exposed, on the nose of the Corris Anticline near Cwm Cadian, in the two small streams which drain into the River Dulas south of Corris, near Trem-afon, (north of Garnedd-wen Station), in the River Dulas (east of Aberllefenni), etc.

The actual junction of the Garnedd-wen Beds and the Mottled Beds is not commonly well exposed in the Corris area; but it may be observed in Nant y Goedwig and in the unnamed stream which runs past the Vicarage, south of Corris Village. In both these localities, and at several places south-westwards as far as Taren y Gesail, the top of the Garnedd-wen Beds consists of a prominent grit-band about 10 to 12 inches thick: as, for example, at Cwm Cadian and in the old level on Taren Cadian. The rocks immediately below this grit-band often consist of alternating thin gritty and dark mudstone layers with a characteristic undulating bedding, which imparts to them a 'wavy' appearance.

The junction of Ordovician and Silurian may be seen within a foot or so in several places north-east of Corris, as, for example, in the Afon Dulas, where it is joined by the Afon Neiriau (east of Aberllefenni), etc. This locality is one where the actual contact between the Mottled Beds and the Garnedd-wen Beds might be examined in detail under favourable conditions.

In the small unnamed stream south of Corris, mentioned above, there is exposed a thin dark shale-band with a pronounced rusty weathering, about 1 inch thick, and about 2 feet above the base of the Mottled Beds. This thin band exhibits the peculiar lithological characters of the band described at Machynlleth, at the same horizon. It breaks up into thin brittle pieces, and is very much weathered etc. In this locality at Corris it has yielded:—

Glyptograptus persculptus Salter.
Mesograptus modestus var. *parvulus* (H. Lapworth).
Climacograptus scalaris var. *miserabilis* Elles & Wood.
Climacograptus scalaris var. *normalis* Lapworth.

The thickness of the Mottled Beds is about 30 to 35 feet, although in some places in the Corris area they appear to be rather thinner; as, for instance, in Nant y Goedwig, in the unnamed stream near the Vicarage, south of Corris, and between Corris and Aberllefenni. In these localities they appear to be not more than 20 feet thick; but north-east of Aberllefenni they regain their normal thickness.

The Mottled Beds are overlain by rusty-weathering shales closely similar to those exposed in the Machynlleth area, and they doubtless correspond to the zone of *Diplograptus acuminatus* and the *Monograptus* spp. Beds as defined in the latter area.

They have not been examined in detail, and even fairly well-preserved graptolites are difficult to extract. They are highly cleaved: the cleavage-planes being practically vertical, while the bedding-planes intersect the cleavage-planes at an acute angle. In all their lithological characters they appear to be precisely similar to the corresponding beds described farther south.

From the old quarries in these beds at Taren y Gesail the following graptolites have been obtained:—

Climacograptus scalaris (Hisinger) *sensu lato.*
Climacograptus tornquisti Elles & Wood.
Glyptograptus tamariscus Nicholson.
Orthograptus mutabilis Elles & Wood.
Petalograptus palmeus (Barrande).
Dimorphograptus confertus var. *swanstoni* (Lapworth).
Monograptus communis (Lapworth).
M. concinnus (?) Lapworth.
M. acinaces Tornquist.
M. triangulatus (Harkness).

From Nant y Goedwig:—

Climacograptus tornquisti Elles & Wood.
Glyptograptus tamariscus Nicholson.
Monograptus acinaces Tornquist.
Monograptus regularis Tornquist.
M. sandersoni Lapworth.
M. triangulatus (Harkness).

From the old quarry in the Dulas Valley immediately north-east of Corris:—

Climacograptus scalaris (Hisinger) *sensu lato.*
Monograptus concinnus (?) Lapworth.
Monograptus acinaces Tornquist.
Orthograptus mutabilis Elles & Wood.

From Nant Llwydiarth near Cymerau, north-east of Aberllefenni:—

Climacograptus hughesi (Nicholson).
Climacograptus scalaris var. *normalis* Lapworth.
Climacograptus tornquisti Elles & Wood.
Glyptograptus tamariscus Nicholson.
Monograptus atavus Jones.
M. communis (Lapworth).
M. communis var. *rostratus* Elles & Wood.
Monograptus concinnus (?) Lapworth.
M. cyphus Lapworth.
M. fimbriatus (Nicholson).
M. gemmatus (Barrande).
M. gregarius Lapworth.
M. incommodus (?) Tornquist.
M. raitzhainiensis (Eisel).
M. revolutus var. *austerus* Tornquist.
M. sandersoni Lapworth.
M. triangulatus (Harkness).

The thickness of the Cwmere Group is about 300 to 350 feet.

Derwen Group.—As at Machynlleth, the rusty-weathering shales of the Cwmere Group are overlain by a characteristic group of pale-grey mudstones, with comparatively thin dark shale-bands which yield graptolites. The change in lithology takes place at the base of the zone of *Mesograptus magnus*, and is one of considerable assistance in surveying. This boundary has been mapped throughout the Corris area.

The Derwen Group has not been examined in detail in the Corris area; but it possesses the same lithological characters as in the area farther south, and there is little doubt that, if investigated in detail, it would reveal the same faunal succession.

From the Derwen Beds at Taren y Gesail, between the two sets of disused quarries, the following graptolites have been obtained:—

Climacograptus hughesi (Nicholson).
Climacograptus scalaris (Hisinger).
Climacograptus scalaris var. *normalis* Lapworth.
Petalograptus minor Elles.
Petalograptus palmeus var. *tenuis* (Barrande).
Monograptus convolutus (Hisinger).
Monograptus decipiens Tornquist.
M. gemmatus (?) (Barrande).
M. lobiferus (M'Coy).
M. regularis (?) Tornquist.
M. tenuis (Portlock).
Monograptus sp.
Rastrites hybridus (Lapworth).

The zone is that of *Monograptus regularis*, as defined at Machynlleth.

From Nant y Goedwig the following were obtained:—

Climacograptus hughesi (Nicholson).
Climacograptus scalaris (Hisinger).
Climacograptus scalaris var. *normalis* Lapworth.
Orthograptus bellulus Tornquist.
Monograptus argutus (?) Lapworth.
Monograptus clingani (Carruthers).
M. convolutus (Hisinger).
M. decipiens Tornquist.
Petalograptus palmeus var. *latus* (Barrande).
Rastrites peregrinus (Barrande).

From Ffridd Newydd, south of Aberllefenni, the following were obtained:—

Climacograptus hughesi (Nicholson).
Climacograptus scalaris (?) (Hisinger).
Petalograptus minor Elles.
Monograptus argutus (?) Lapworth.
M. convolutus (Hisinger).
Monograptus decipiens Tornquist.
M. lobiferus (M'Coy).
M. regularis Tornquist.
M. tenuis (Portlock).
Rastrites hybridus (Lapworth).

From Nant Cwm Cadian the following were obtained:—

Monograptus convolutus (Hisinger).
M lobiferus (M'Coy).
Monograptus regularis Tornquist.
Climacograptus sp.

In the same stream-section, a short distance above the *Monograptus-convolutus* Beds, the following graptolites were collected:—

Monograptus halli (Barrande).
M. sedgwicki (Portlock).
Monograptus tenuis (Portlock).
Climacograptus scalaris (Hisinger).

The total thickness of the Derwen Beds is rather less than 200 feet.

Ystwyth Stage.

So far as they have been investigated in this area, the beds of the Ystwyth Stage consist of pale greyish-blue slaty mudstones, with numerous irregularly laminated grit-bands measuring up to 1 or 3 inches in thickness. The laminated grit-bands have usually a false-bedded appearance.

Immediately above the base at Taren y Gesail are disused quarries in a slaty group belonging to this stage. The greyish-blue slaty mudstones which have been quarried are precisely similar to those that have been quarried farther south at Cwm y Gôf and Cwm Rhaiadr (described in the Machynlleth paper). They contain paler mudstone-bands and some bands of grit.

At a somewhat higher horizon, a similar slaty group in the Ystwyth Stage has been extensively quarried south of Corris, as, for example, in the Era and Rhiw'r-gwreiddyn Slate-Quarries near Esgairgeiliog. Here again the lithological type is a greyish-blue slaty mudstone, with paler bands and some laminated gritty seams.

The transition from the Derwen Beds to the Ystwyth Stage is marked by the gradual incoming of siliceous and gritty bands. They rapidly increase in number, and within a few feet become well-marked grit-bands. The base of the Ystwyth Stage has been taken, for convenience in mapping, where the gritty bands become characteristic. Actually, this is some distance above the band which yields *Monograptus sedgwicki*. It should be pointed out that the boundary is, in many ways, an unsatisfactory one.

Note on the Outcrop of the Valentian Rocks.

Throughout the Corris-Aberllefenni area, the outcrops of the various members of the Valentian Series make the characteristic topographical features described farther south.[1] The comparatively soft shales of the Cwmere Group form a hollow flanked on one side by the rough craggy ground of the Garnedd-wen Mudstones, and on the other by the well-marked escarpment of the Derwen Group, capped in most cases by the basal beds of the Ystwyth Stage. This feature is particularly well displayed when the rocks cross a spur or ridge between two valleys.

V. Detailed Description of the Structure.

Folding.

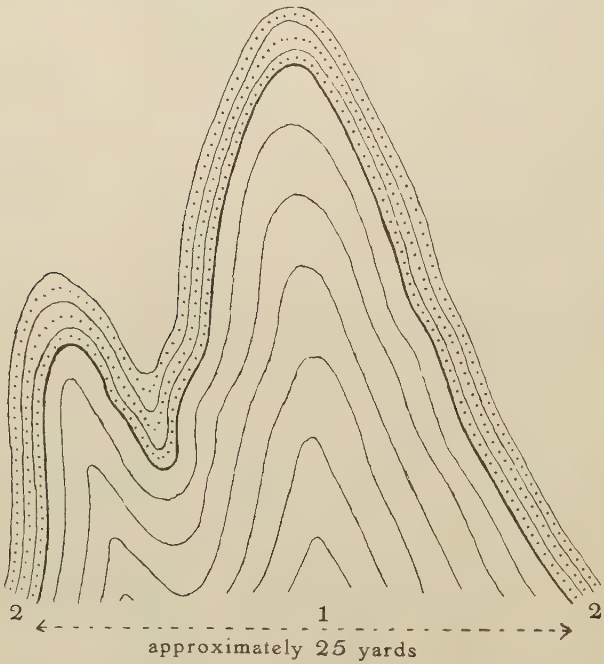
The area lies on the south-eastern flank of the Harlech Dome, and the general trend of the strata is determined by that major structure. As a result, the general strike of the beds is from south-west to north-east. The beds dip south-eastwards, the dip varying from about 40° to practically vertical. The lowest dips are usually found along the margin of the volcanic rocks—the average dip there being about 45°. South-eastwards the dip gradually steepens,

[1] O. T. Jones & W. J. Pugh, Q. J. G. S. vol. lxxi (1915-16) fig. 1, p. 348.

until along the outcrop of the Narrow Vein it may be as much as 70°: as, for instance, at Aberllefenni. This steep dip is normally maintained or even increased, until the outcrop of the Derwen Beds is reached: for example, the Cwmere Beds at Brynllwyd Quarry, south of Corris, dip south-eastwards at 88°. The dip then gradually decreases as we come upon the outcrops of the Ystwyth Stage.

Just as the Harlech Dome itself is crossed by folds minor in comparison with that great anticlinal structure itself, so in the

Fig. 4.—*Diagrammatic sketch of the Corris Anticline, as seen in the southernmost quarry at Braich-goch, Corris.*



1 = Narrow slate-vein. 2 = Garnedd-wen Beds (mudstones with thin grit-bands).

Corris area there are folds which trend transversely to the normal strike of the beds, and cause considerable deviations in the general direction of the outcrops.

The area is crossed by two important anticlinal structures, one in the west which we may call the Corris Anticline, and the other farther east which we may call the Aberllefenni Anticline. The axes of these two folds trend north-north-east and south-south-west, and in some places approximately north and south.

Of these two anticlinal structures, the larger and more important is the Corris Anticline. It is the northward continuation of the Cefn Maesmawr Anticline, which was described in the Machynlleth area (see fig. 5, p. 534). Although this anticlinal structure persists right through from the River Dyfi to Corris, its character changes considerably northwards. Immediately south of the Dyfi, the Cefn Maesmawr Anticline is overfolded towards the east, and the eastern limb is in most places replaced by a well-marked strike-fault which has been called the Brwyno Overthrust. At Corris this overthrust has disappeared, and, in addition, the anticlinal structure is not markedly asymmetrical.

The character of the Corris Anticline is well brought out by the outcrops of the various bands which have been mapped: as, for instance, the zone of *Glyptograptus persculptus* at Cwm Cadian and the thick grit-band in the Garnedd-wen Beds on Mynydd Braich-goch, etc. The nose of the anticline is particularly well seen in the southernmost Braich-goch slate-quarry (see fig. 4, p. 532).

The anticlinal structure seems scarcely to make itself felt on the outcrop of the Nod Glas, and this feature has been observed, in addition, at several localities outside the area at present described. While the outcrops of the Pont Erwyd Stage and the Abercorris Group may indicate pronounced folding, this is rarely revealed by the outcrop of the Nod Glas, which runs in a general south-westerly and north-easterly direction with remarkably few deviations.

This curious variation in folding in different beds is difficult to explain, unless it be that the folds diminish in intensity northwards, or that the massive, compact Abercwmeiddaw Mudstones protect the Nod Glas from the repeated folding experienced by the higher beds.

It is probably the Corris anticlinal axis which brings in the outcrop of the volcanic rocks on the north-western side of Mynydd y Waun. At the latter place the western limb of the structure is replaced by a well-marked strike-fault.

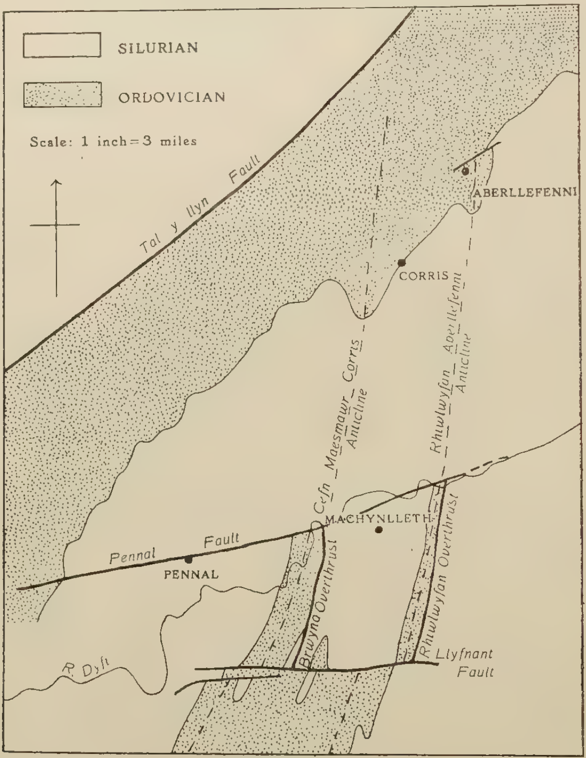
The Aberllefenni Anticline is not so important a structural feature as the Corris Anticline. It is however, in all probability, the northward continuation of the Rhiwlwyfan Anticline recorded at Machynlleth (see fig. 5). There is no indication of the Rhiwlwyfan Overthrust which marks the eastern limb of the anticline farther south, nor is the Aberllefenni Anticline markedly asymmetrical. The anticlinal structure appears to die out immediately north of Aberllefenni, for there is no indication of the fold in the outcrops of the Narrow Vein and the Red Vein as they cross over the ridge of Foel Crochan, north of Aberllefenni: in fact, the fold appears to die out so soon as the Aberllefenni strike-fault is reached.

The small synclinal structure which intervenes between the above-mentioned anticlines is the northern extension of the Glaspwll Syncline at Machynlleth; while the broad synclinorium west of the Corris anticlinal axis may be correlated with the synclinorium farther south, the eastern and western limbs of which

are represented by the outcrops of the Pont Erwyd Stage at Derwenlas and Pant yr On, west of Pennal, respectively (see fig. 5, below).

There is a certain amount of minor folding, as revealed, for example, by the outcrops of the Pont Erwyd Stage between Taren y Gesail and Cwm Cadian; but this appears to die out northwards. There is little doubt that, from the point of view of geological

Fig. 5.—*Sketch-map illustrating the general geological structure of the area between Corris and Machynlleth.*



structure, the area is much less complex than that described farther south about Machynlleth.

All the folds in the Corris area show a well-marked southerly pitch, as opposed to the northerly pitch at Machynlleth. Whenever it is possible to take direct observations of the pitch, the amount appears high; for example, when the outcrop of the zone of *Glyptograptus persculptus* crosses the axis of the Corris Anticline at Cwm Cadian, the pitch is about 35°, and again where the well-marked grit-band in the Garnedd-wen Beds crops out on

the north side of Nant y Goedwig, the pitch is again 35°. In fact, in most localities where it is possible to take direct observations of the pitch, the values vary between 30° and 35° and rarely less. However, it is unlikely that this value is maintained continuously along the axis of the folds. It is probable that the crests of the folds are of an undulatory character: that is, at one point the pitch is considerable, then diminishes, and then steepens again. If that be so, then the average pitch in the area is considerably less than 30° or 35°.

In this respect it is interesting to observe the form of the outcrops of successive rock-groups in the Corris Anticline. The outcrop of so well-defined a band as the *persculptus* zone makes a broad V pointing southwards indicating a strong southerly pitch. The equally conspicuous outcrop of the grit-band in the Garnedd-wen Beds below makes a narrow V, such indeed, that for some distance the outcrops in both limbs of the fold are approximately parallel one to the other. This feature is again well shown in the form of the outcrop of the Narrow Vein farther north, where the outcrops on the two limbs of the anticline are practically parallel for a distance of over half a mile. The western outcrop of the Narrow Vein in this locality is capable of accurate mapping, for it is continuously exposed in a series of open-air workings. The eastern limb is not quite so well exposed for part of its outcrop; but there can be no doubt of its location within a few feet, because exposures of the characteristic beds above and below are numerous. It is possible, however, that part of the Narrow Vein may be cut out by faulting on this eastern limb, but I have found no evidence of this.

Taking further into account the width of outcrop of the various groups along the axis of the Corris Anticline, it would appear that, between the outcrops of the *persculptus* zone and the prominent grit-band on Mynydd Braich-goch, the average pitch is rather more than 30°; while between the grit-band and the Narrow Vein, the average pitch cannot be more than from 16° to 18°. Farther north along the axis the pitch would appear to be still less for some distance.

It is considered, therefore, that the amount of the pitch varies considerably along the axis of the Corris Anticline, and it is possible that this feature is repeated along the axes of the other folds in the area.

It will be observed, further, from an examination of the form of the outcrop of the Narrow Vein in the Corris Anticline about the Braich-goch Quarries, that there is fairly considerable torsion of the anticlinal axis. The direction of axis as revealed by the outcrops of the *persculptus* band and the grit-band mentioned above, indicates a direction a few degrees east of north; while for some distance in the Braich-goch quarrying area the axis trends distinctly west of north. Subsequently the axis veers to the east of north again, as revealed by the location of the volcanic outcrop on the north-western slopes of Mynydd y Waun.

Faulting.

Strike-faults.—The northern margin of the area described is bounded by the great Tal-y-llyn or Bala Fault, which follows the deep valley of Tal-y-llyn; but no investigations have been carried out on this fault itself.

However, by mapping the upper limit of the volcanic rocks on Craig y Llam, the presence of several small strike-faults has been proved. They trend approximately parallel to the main Tal-y-llyn Fault, and are in all probability closely related to it. These relatively small faults make conspicuous features when the junction of the Craig y Llam and Hengae Groups is followed. Each of them affects the outcrop of the volcanic rocks in the same way, only with slightly differing results. They act as repeating faults, and the rocks are thrown up on their south-eastern side. As to whether the movement is mainly a vertical or a lateral displacement, it is difficult to decide definitely.

The presence of these parallel strike-faults leads one to believe that the Tal-y-llyn Fault will be found in this region, not to consist of a single fracture, but rather more probably of a belt of parallel faults ('shatter-belt').

The Waun Fault.—The western margin of the volcanic rocks on the north-western slopes of Mynydd y Waun is defined by a well-marked strike-fault which is shown on the 1-inch Geological Survey Map, Old Series, No. 59 N.E. The fault runs along a marshy hollow between Mynydd y Waun and Craig y Llam. In the middle of this depression the crags of volcanic rocks end off very abruptly. When seen north-eastwards from Mynyddd Fron-fraith, this line of crags with abrupt slopes facing north-westwards presents a very characteristic topographical feature.

This fault acts in the same way as the small strike-faults described on Craig y Llam.

The Aberllefenni Fault.—At Aberllefenni there is a well-marked fault, which affects the outcrops of the Abercorris Group and the Pont Erwyd Stage. As a result, the Narrow Vein occurs twice on the south side of the Llefenni Valley. Its effects may be compared with those of the strike-faults mentioned above. It is of the nature of a repeating fault, and the rocks are thrown up on the south-eastern side. The fault-plane probably is steeply inclined south-eastwards.

It may be the south-western extension of this fault that causes the comparatively narrow outcrop of the Abercwmeiddaw Group, north-west of Corris.

The transverse faults.—In the extreme north of the area the margin of the volcanic rocks is interrupted by two relatively unimportant dip-faults. They make conspicuous notches on the boundary between the volcanic rocks and the Ceiswyn Mudstones.

They trend north-west and south-east, and faults with a similar direction have been located by Prof. A. H. Cox & Mr. A. K. Wells in the Arthog-Dolgelly district, and by Miss G. L. Elles in the Bala country.

Both fault-planes are inclined south-westwards, the more northerly one at about 60°. Both possess a small downthrow to the north.

The cleavage.—All the rocks in the Corris-Aberllefenni area are affected by a very pronounced cleavage, although the degree to which they have been affected has depended to some extent upon the physical characters of the rocks themselves. The coarser-grained and less homogeneous rocks have not yielded so much to the compressional movements.

The cleavage-planes trend almost exactly parallel to the strike of the beds, but are not so greatly affected by the minor folding. They are steeply inclined or practically vertical, as a general rule. The average inclination over much of the area is about 80° to 85° south-eastwards, but the inclination diminishes somewhat with the diminution in dip as the margin of the volcanic rocks is approached. In the dark slaty group at the base of the Ceiswyn Beds, immediately above the volcanic rocks: as, for example, at the head of the Llefenni Valley, the cleavage-planes are inclined south-eastwards at 60°.

VI. Comparison with other Areas.

It is proposed to give some general comparisons with other areas in the case of the Ordovician rocks alone. The Valentian rocks are closely similar to those described farther south in the Machynlleth area, where the succession has been compared in detail with that obtaining in other districts.

Central Wales.—The Ty'n-y-maen Group of the Plynlimon Stage, described at Machynlleth, corresponds with the upper part only of the Garnedd-wen Mudstones at Corris. The lithological characters ars closely similar in both areas.

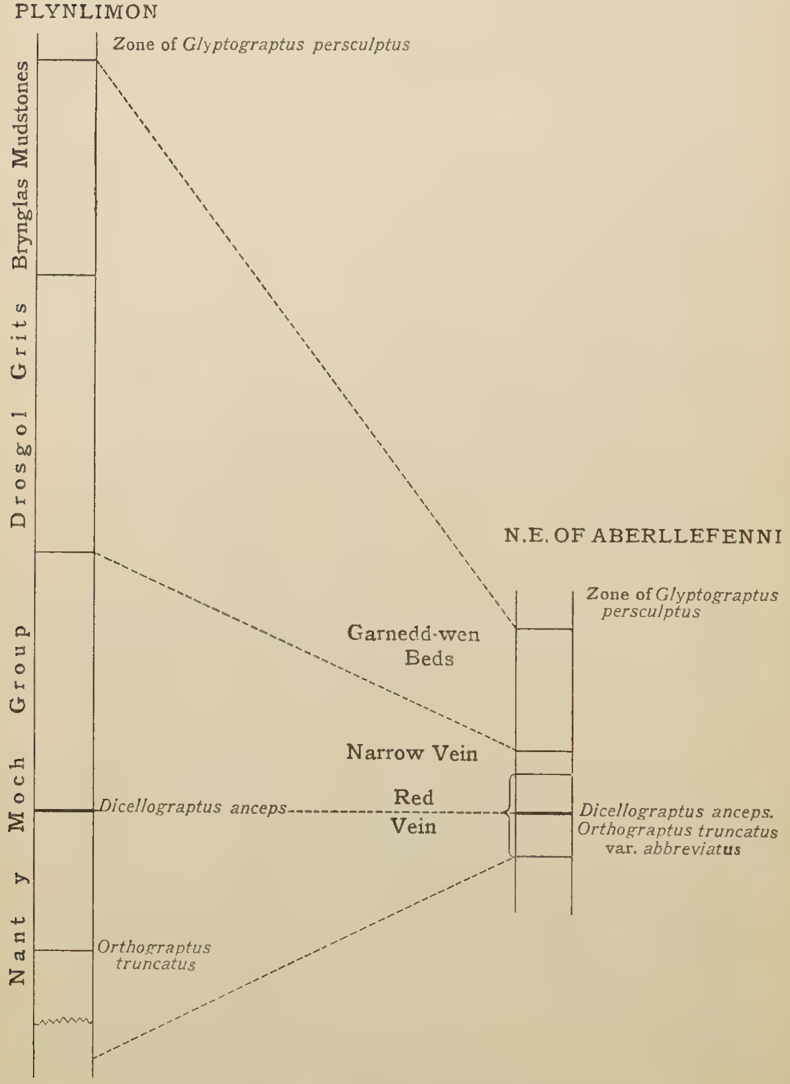
There is no doubt that the Abercorris Group may be correlated with the Plynlimon Stage at Plynlimon.[1] From the basal group of the Plynlimon Stage, namely the Nant-y-Moch Flags, Prof. O. T. Jones records the following graptolites:—

Dicellograptus anceps.
Orthograptus truncatus.
Orthograptus cf. *mutabilis.*
Climacograptus scalaris var. *miserabilis.*

The fauna is the same as that of the Red Vein at Corris. The Red Vein, and probably the Narrow Vein, may, therefore, be correlated with the Nant-y-Moch Flags. The Garnedd-wen Beds are equivalent to the Drosgol and Brynglas Group at Plynlimon,

[1] O. T. Jones, Q. J. G. S. vol. lxv (1909) p. 468.

Fig. 6.—*Comparative sections illustrating the relation of the sequence north-east of Aberllefenni with that at Plynlimon.*



[Vertical scale: 1 inch = 800 feet.]

the lithological characters of the groups in both areas being practically identical.

When the thicknesses of these groups are compared, however, there are many striking differences. Prof. O. T. Jones informs me that he considers the Brynglas and Drosgol Groups to be approximately 900 and 1150 feet thick respectively: that is, a total thickness of 2050 feet. The Garnedd-wen Beds in the south-western part of the Corris area approximate to that total thickness; but there is a marked diminution in thickness in the eastern part of the area, where the Garnedd-wen Beds are not more than 500 feet thick, probably rather less.

The Nant-y-Moch Group is about 2000 feet thick, and even then the base of the group is not exposed. The Red Vein and Narrow Vein are only about 400 feet thick throughout the Corris-Aberllefenni area.

It is, of course, possible that the Narrow Vein may be a development of the lower part of the Drosgol Group; but that does not materially affect the values given, for the Narrow Vein rarely, if ever, exceeds 60 feet in thickness.

The Plynlimon Stage is about 4000 feet thick, as exposed at Plynlimon. At Corris the total thickness of the corresponding Abercorris Group varies from 2400 feet in the west to 900 feet in the east. The point where the Abercorris Group diminishes in thickness to about 900 feet is approximately 16 miles due north of Plynlimon (see fig. 6, p. 538).

Further, it is interesting to observe that at Plynlimon, *Dicellograptus anceps* occurs in a band about 600 feet above the shales which yield *Orthograptus truncatus*. At Corris, *D. anceps* is found in a band which is considered to be a short distance, probably only a few feet, above the shales that yield *O. truncatus* var. *abbreviatus* in such abundance.

It will, therefore, be seen that the correspondence between the two areas is very close, despite the great difference in thickness of the rock-groups.

The Bala area.—The lower part of the Ceiswyn Beds recalls in many ways the lithological characters of the Nant Hir Shales which overlie the Ordovician volcanic rocks west of Bala.[1] At Corris, however, there is no trace of the Derfel Limestone recorded at Bala. The rocks immediately above the volcanics at Corris are well exposed, and so it would appear that that highly characteristic limestone-band dies out before this area is reached.

At present, it is difficult definitely to correlate any of the groups established at Corris with those described at Bala, although the two areas are only about 20 miles apart. The Foel-y-Dinas Mudstones yielding the *Phacops-mucronatus* fauna are probably equivalent in general to the Garnedd-wen Beds, since the latter, north-east of the area at present described, yield *Ph. mucronatus.*

[1] G. L. Elles, Q. J. G. S. vol. lxxviii (1922) p. 132.

Presumably, the Rhiwlas Limestones and Mudstones correspond to the basal part of the Abercwmeiddaw Group; but the faunas obtained are quite distinct.

In the Bala country, ash-bands occur above the main mass of the volcanic rocks. There is no evidence of similar ash-bands in the Corris area, nor of any of the well-marked limestone-bands which are so characteristic and fossiliferous at Bala.

Girvan area.[1]—There are many points of similarity between the succession at Girvan and that of Corris. The fauna obtained from the Abercwmeiddaw Mudstones recalls at once the fauna obtained by the late Prof. Charles Lapworth from the highest beds of his Whitehouse Group: namely, the *Dionide* Band. This highly characteristic band at Girvan is underlain immediately by the zone of *Dicellograptus complanatus*.

It appears, therefore, possible that the beds immediately below the *Cyclopyge* Beds in the Abercwmeiddaw Group correspond approximately to the *Dicellograptus-complanatus* Zone on the graptolitic time-scale.

In the lower part of the Whitehouse Group, Prof. Lapworth recorded from black shales *Pleurograptus linearis*, *Dicellograptus morrisi*, *D. forchammeri*, etc. The fauna of these graptolitic shales recalls that of the Nod Glas at Corris; but the presence of *Dicranograptus clingani* in the latter area suggests a somewhat lower horizon: namely, the highest part of the Ardwell Beds at Girvan. Hence at Corris it is possible that the *Pleurograptus-linearis* Zone may be represented by the very highest black shales of the Nod Glas, and perhaps that part of the Abercwmeiddaw Mudstones which lies beneath the *Cyclopyge* Beds.

There is some difficulty in subdividing the Upper Ordovician rocks in the Corris area into the usual Ashgillian and Caradocian Stages, and consequently I have not attempted to do so.

The Conway area.[2]—At Conway, in the Deganwy or *Phacops* Mudstones, *Ph. mucronatus* has been found about 7 feet above a shale-band yielding *Orthograptus truncatus* var. *abbreviatus*. It will be recalled that at Corris the Red Vein yields that graptolite, together with *Dicellograptus anceps*. Outside the Corris area, towards Dinas Mawddwy, *Phacops mucronatus* occurs in the lower part of the Garnedd-wen Beds immediately overlying the Narrow Vein. The Deganwy Mudstones, therefore, appear to correspond in stratigraphical position with the Abercorris Group. If that be so, then there is a very striking difference in thickness. The Deganwy Mudstones are only 80 feet thick; but the Abercorris Group varies from 2400 to 900 feet.

Underlying the Deganwy Mudstones at Conway are the *Trinucleus* or Bodeidda Mudstones, and these appear to possess

[1] C. Lapworth, Q. J. G. S. vol. xxxviii (1882) p. 537.
[2] G. L. Elles, *ibid.* vol. lxv (1909) p. 169.

lithological characters very similar to those of the Abercwmeiddaw Mudstones which underlie the Abercorris Group. At Corris they yield most commonly species of *Trinucleus*; but there are many differences in fauna between the two groups. If the Bodeidda Mudstones are correlated tentatively with the Abercwmeiddaw Group, there is again a marked difference in thickness from 350 feet at Conway to 1500 feet at Corris.

The highest beds of the Cadnant Shales may, perhaps, be correlated with part of the Nod Glas, but there are again many differences in fauna. The *Dicellograpti* which are so abundant at Corris appear to be absent at Conway, and there is no indication in the latter area of those graptolites which at Corris suggest the somewhat higher zone of *Pleurograptus linearis*.

In conclusion, I wish to express my thanks to Prof. O. T. Jones, who has given me much valuable advice and assistance in the identification of the fossils, and much encouragement during the progress of the investigation; also to Mr. G. J. Williams, I.S.O., who, in the early stages of the work, informed me of several localities where he had collected fossils.

EXPLANATION OF PLATE XXVII.

Geological map of the district around Corris and Aberllefenni, on the scale of 2 inches to the mile, or 1 : 31,680.

DISCUSSION ON THE TWO FOREGOING PAPERS.

Miss G. L. ELLES said that she was more particularly interested in the questions connected with the Black-Shale Group in the two areas, and in the occurrence of the *Dionide* fauna. Mr. King's paper dealt with an area which was close to the Bala country, where no Black Shales occur at the horizon that he had noted; nevertheless, this apparent discrepancy probably seems greater than it actually is, for at the top of the Allt-ddw Mudstones these graptolitic shale-bands do occur intercalated in the mudstones, showing that the conditions for the accumulation of graptolite-shales were not very far away even there. What these conditions were was another question; Mr. King considered that his Black Shales had accumulated under 'lagoon' conditions. In the opinion of the speaker that depended upon the meaning of the term 'lagoon': if it meant merely shallow, quiet water, she would agree absolutely; but, if it implied restriction in communication with the open sea, she would disagree just as absolutely. She did not think that any worker on graptolite-shales at the present day considered them deep-sea deposits: the factor that controlled their deposition was not depth as depth, but the other factors that go with depth, especially quietness of the waters, as indicated by the perfect condition in which these delicate little organisms are found. This had been pointed out as long ago as 1897 by the late Prof. Charles Lapworth,

and accorded well with their distribution in the deeper parts of the epicontinental seas where these conditions were best attained; in certain circumstances, however, similar conditions might be found in quiet, shallow water. The world-wide distribution of the graptolites certainly seemed to necessitate free communication with the open ocean, though perhaps, again in exceptional circumstances, graptolite-shales might accumulate in areas where there was only restricted communication. It might, however, be expected that the fossils would then exhibit some abnormality. With regard to the Black Shales in Prof. Pugh's country, they appeared to the speaker to belong very much to the same horizon as those described by Mr. King (top of the *Pleurograptus-linearis* Zone), and that would seem to fit in better with the succession than their relegation to a lower horizon, which would make it difficult to see what represented the *P.-linearis* Zone.

Prof. Pugh's discovery of the *Dionide* fauna of the Whitehouse Beds was most interesting and important, as it afforded another instance of the invasion of the Welsh area by the Scottish type of Ordovician fauna. This had been first noted in the resemblance of the fauna of Prof. Fearnsides's Derfel Limestone to that of the Stinchar Limestone. There could be little doubt that the Ashgillian fauna as a whole was derived from this Scottish type of fauna, and therefore this discovery of Prof. Pugh's was a further indication of the gradual spread of that fauna into Wales.

Prof. O. T. Jones said that he did not entirely agree with the idea that the graptolite-shales were deposited in lagoons, although it was evident that they were laid down in shallow water. The difference in the folding at different horizons showed that there was much movement along the bedding-planes, especially of the softer strata. The terms Ashgillian and Caradocian are not yet sufficiently well known to allow of their general application, and consequently it is preferable (in the existing state of knowledge) to use local names for the formations, as had been done by Prof. Pugh.

The Secretary read the following communication received from Mr. E. E. L. Dixon:—

'In 1910 I had occasion to go through much of the literature on radiolarian rocks, and, of course, came to the classic work of B. N. Peach & J. Horne on the Southern Uplands. I had been led to the conclusion that radiolarian cherts of the thinly wedge-bedded, striped type were very shallow-water ('lagoon') deposits, not those of deep seas, and, for comparison, I was looking for cherts of indubitably deep-sea origin. Those of the Southern Uplands had been claimed to be such, and the association of the cherts there with graptolite-shales was, if I remember aright (I speak without the book), held to be confirmation of the deep-sea origin of both. But, as some of the cherts were evidently (from the description) similar, in essential features, to those of the Culm, which I believed to be lagoon-deposits, I was led to examine the credentials of graptolite-beds. Their claim to be of oceanic origin proved to be even less well-substantiated than that of the cherts, for the simple reason that, whereas the widespread radiolarian deposits of the present day are confined to deep seas, no recent formation corresponding without doubt to

graptolite-shales is known. The fineness of the sediment counts for nothing, as it may be paralleled in certain unquestionably shallow-water groups: for instance, some beds in *Modiola*-phases. The same may be said of the organic remains, restricted to plankton and nekton, but often teeming in individuals. Under lagoon-conditions, I have suggested, such kinds of sediment and organisms, though unusual in ordinary shallow-water beds, would tend to accumulate.

'Radiolarian cherts (of the striped type) and graptolite-shales go together, in my opinion, in their relations to standard deposits and to the contemporaneous shore-lines. So far as radiolarian rocks are concerned, I have been able to get further evidence; but, as regards graptolite-shales, I have had, perforce, to be content with studying the work of others. In 1911 Arthur Vaughan, when collaborating with Prof. S. H. Reynolds on Burrington Combe, considered the rapid variation shown by graptolites to be more probably the result of an in-shore life than of a pelagic existence; but a shallow-water origin has rarely been ascribed to particular graptolite-beds: I can recall merely one example, described about 1921 by G. T. Trœdsson. On the other hand, the association in some places, such as Tourmakeady (described in 1909 by C. I. Gardiner & S. H. Reynolds) of coarse grits with radiolarian cherts and graptolite-slates is irreconcilable with sedimentation in deep seas, as, in the case of the cherts, had been pointed out already by A. J. Jukes-Browne.

'The kind of evidence that has been desired, so far in vain, has been a determination by field-mapping of the relations of a graptolitic deposit to the shelly beds on the same horizon, and to the contemporaneous shore-line. Hitherto it has been assumed that the graptolitic phase indicates the deeper water. If, as I understand, Mr. King has obtained proof by his mapping that the area occupied by certain graptolite-beds lies between that of the contemporaneous shelly beds and the independently-known position of the shore-line, he has made an important step towards harmonizing a number of anomalous observations in a way which may vitally affect our conceptions of Older Palæozoic geography.'

Prof. O. Holtedahl was interested to hear Mr. King's suggestion that the graptolitic shales were shallow-water sediments because graptolite-shales have quite commonly, until recent times, been regarded as indicating deep-water conditions. The speaker had, as a result of his studies on Ordovician sediments of a certain district of the Christiania region (published in 1909), come to the conclusion that the graptolite-shales there were not of deep-water origin. Prof. J. Walther had, before that time, expressed the opinion that the black shales, so commonly found in the Cambro-Silurian formations of North-Western Europe, were deposited in lagoon-like bodies of water; but we must certainly assume these to have been quite extensive epicontinental seas. The sea in which the Cambrian alum-shales of the Scandinavian Peninsula were deposited must have had a length at least comparable to that of the peninsula itself. As to the stratigraphical conditions just at the Ordovician-Silurian boundary, it was interesting to notice how they are in the Christiania region very similar to those mentioned by Mr. King. In some districts there seems to be an unbroken succession, but with passage-beds of a very coarse character, while in others distinct breaks are noted.

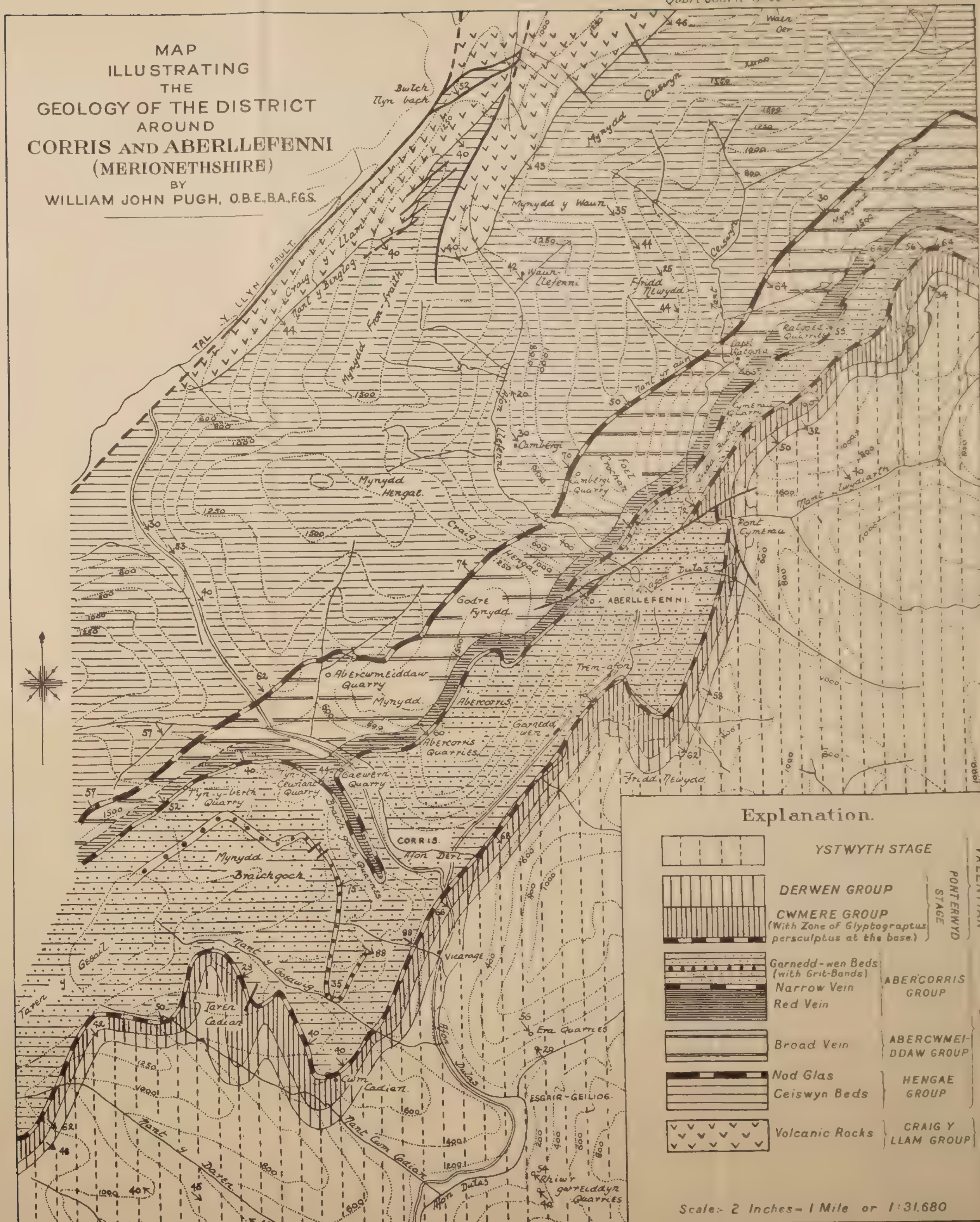
Prof. W. G. Fearnsides said that, with regard to Mr. Dixon's suggestion that graptolite-bearing mudstones represent a 'lagoon'

phase of Lower Palæozoic sedimentation, he thought the term lagoon an unfortunate misnomer. Those who have searched particular zones of graptolites in widely-separated localities, as, for example, the Valentian of Wales, the South of Scotland, Scandinavia, etc., well know that the lithology of the individual beds which hold the fossils is as characteristic as the specific features of the graptolites, and as widespread. The worker who knows his rocks at one place will always be quick to find the fossils for which he is searching at a new locality, although he may be hundreds of miles away from the district where he got his knowledge. The 'lagoon' over the floor of which the famous continuous 4-inch band with *Monograptus argenteus* was deposited must have been about as wide as the Mediterranean Sea. The speaker could, however, agree that the graptolites which one occasionally obtains from the blue and blue-black mudstones, interstratified with volcanic ashes and calcareous shelly beds all through the Ordovician formation in Merioneth, are a meagre and ill-nourished lot, and that some explanation of the dwarfed character of these faunas is required.

Having experience that, in another district, in sandy calcareous rocks which occur not far from the Ashgillian–Caradocian boundary, certain species of the shelly fossils, which Mr. King had exhibited as representative of his collections from the sandy beds above and below the black graptolite-shales of the South-Western Berwyns, occur associated together, he expressed the hope that, in the paper when published, Mr. King would give information distinguishing between the species which he regards as long-range fossils characteristic of a particular kind of habitat, and the other mutating forms which he has found distinctive of particular geological horizons and really useful for zonal work.

The Chairman (Prof. W. W. Watts) congratulated both Authors on the presentation of the chief points of the two papers in less than an hour. He regretted that Dr. A. Wade was unable to be present to defend his reference of the Gwern-y-Brain shales and limestone to the Ashgillian. Mr. King had confirmed Dr. Wade's recognition of a peculiar fauna in these beds, but referred it to condition instead of age. The speaker found it difficult to understand what were the modern representatives of the areas in which 'lagoon phases' were supposed to have been deposited. He was inclined to suggest that 'Black Sea conditions' may have prevailed during the deposition of the Gwern-y-Brain group.

Mr. King, in reply, said that the conditions of deposition of the black shales in question differed somewhat from the normal graptolitic type. He did not suggest that all graptolite-shales were necessarily of the same origin. He understood that the 'lagoons' of Mr. Dixon were not in any way similar to the small lagoons of coral-islands, but that they were essentially shallow-water areas which were, for some reason, completely cut off from the supply of normal sediment, and in which the conditions were


MAP
ILLUSTRATING
THE
GEOLOGY OF THE DISTRICT
AROUND
CORRIS AND ABERLLEFENNI
(MERIONETHSHIRE)
BY
WILLIAM JOHN PUGH, O.B.E., B.A., F.G.S.
TAL Y LLYN FAULT
Bwlch llyn bach
Mynydd Ceiswyn
Mynydd y Waun
Waun Llefenni
Ffridd Newydd
Capel Ratgoed
Ratgoed Quarries
Nant yr Alun
Cymerau Quarry
Nant Llwydiarth
Pont Cymerau
Cambergi
Cambergi Quarry
Mynydd Hengae
Craig Hengae
ABERLLEFENNI
Afon Dulas
Godre Fynydd
Trem-afon
Abercwmeiddaw Quarry
Mynydd Abercorris
Garnedd-wen
Abercorris Quarries
Ffridd Newydd
Tyn-y-berth Quarry
Tyn-y-Ceunant Quarry
Gaewern Quarry
Braich Goch Quarries
CORRIS
Afon Deri
Mynydd Braichgoch
Nant y Gogawig
Vicarage
Taren Cadian
Cwm Cadian
Nant Cwm Cadian
Era Quarries
ESGAIR-GEILIOG
Afon Dulas
Rhiw'r gwreiddyn Quarries
Nant y Darren
W. J. P.
Explanation.
YSTWYTH STAGE
DERWEN GROUP
CWMERE GROUP (With Zone of Glyptograptus persculptus at the base.)
PONTERWYD STAGE
VALENTIAN
Garnedd-wen Beds (with Grit-Bands)
Narrow Vein
Red Vein
ABERCORRIS GROUP
Broad Vein
ABERCWMEIDDAW GROUP
Nod Glas
Ceiswyn Beds
HENGAE GROUP
BALA
Volcanic Rocks
CRAIG Y LLAM GROUP
LLANDEILO
Scale:- 2 Inches = 1 Mile or 1:31,680

unfavourable for the normal type of fauna. It was thought that the black shales in question were formed under these conditions.

With regard to the advisability of using the term Ashgillian in this area, it was clear that the *Phillipsinella* Beds contained the same fauna as the Lower Ashgillian of Cautley and Coniston (as described by Prof. J. E. Marr), and therefore the Berwyn strata had as much right to be called Ashgillian as the beds in the type-areas.

Prof. Pugh, in reply, stated that, while many of the graptolites in the black shales of the Nod Glas suggested the zone of *Pleurograptus linearis*, there occurred, towards the base of the shales, *Dicranograptus clingani*; and this had led him to suggest tentatively that the shales may represent the junction between the zones of *D. clingani* and *P. linearis*. With regard to the variation in folding in different beds, the Nod Glas afforded ample evidence of shearing and slipping.

20. *A* Micrometric Study *of the* St. Austell Granite (Cornwall). By William Alfred Richardson, B.Sc.(Eng.), M.Sc., F.G.S. (Read December 20th, 1922.)

Contents.

I. Introduction.

The St. Austell granite-mass has attracted considerable attention in the past, because of the economic importance of its mineral deposits and the petrological problems that arise out of the wonderful display of pneumatolytic activity manifested in the district. The principal references to the literature are given in the footnote,[1] and since these contain full bibliographies, it is unnecessary to compile another for the purpose of this paper.

Two reasons induced me to undertake this work. In the first place, it appeared desirable to develop and apply to a coarse-grained igneous rock-mass quantitative microscopic methods. Secondly, it seemed probable that much light could be thrown upon the problems of the St. Austell granite by quantitative and qualitative data obtained from a larger number of representative slides than has been available hitherto. A preliminary investigation in the field soon revealed that the district presented some disadvantages in the application of the method, owing to the occasional occurrence of very coarse porphyritic structure in the granite; but, at the same time, it was evident that the results would outweigh a little uncertainty arising from this difficulty.

The present paper deals solely with the granite, and all post-consolidation and metamorphic changes are excluded from its scope. The aim has been to ascertain what evidence exists of differentiation and variation in the original rock. Certain pneumatolytic effects have been generally recognized as inextricably bound up with stages in the intrusion and crystallization of the original magma, and such, of course, come within the purview of the work. In the choice of material in the field care was taken to

[1] 'The Geology of the Country around Bodmin & St. Austell' (Explanation of Sheet 347) Mem. Geol. Surv. 1909; J. A. Howe, 'A Handbook to the Collection of Kaolin, China-Clay, & China-Stone in the Museum of Practical Geology' Mem. Geol. Surv. 1914; T. C. F. Hall, 'The Petrology of the St. Austell Granite' Proc. Geol. Assoc. vol. xxv (1914) pp. 180–92.

avoid spots of intense secondary changes, and specimens were chosen only from good exposures where the general character of the rock could be ascertained, and typical granite-specimens selected. Further, all slides were subjected to a preliminary examination, and, if any showed excessive greisenization or secondary tourmalinization, or were in any respect abnormal samples, they were rejected.

The samples, as finally chosen, represent altogether fifty localities on the main intrusion, besides a few, treated separately, on outlying satellitic masses. The distribution of these localities is shown by reference-numbers (which are also given with the locality-names in Table IV, facing p. 552) on the map (fig. 1, p. 548). The more northerly areas, outlying among Red and Conce Moors, did not provide good exposures, and all surface-blocks appeared to be modified, so this district is not included in the work.

It was found that the rock-types fell very closely into four distinct areas, and, in order to facilitate later description, it will be useful to anticipate the results and define these areas here:—

(*a*) The Retew Area, the small portion of the exposure west of the River Fal.
(*b*) The St. Stephen Area, included between the River Fal and a line drawn northwards through St. Stephen's Beacon.
(*c*) The Hensbarrow Area, stretching from St. Stephen's Beacon nearly to the Luxullyan Valley.
(*d*) The Luxullyan Area, including all the mass cropping out east of the Luxullyan River, and a thin strip of country to the west of it.

The boundary-lines of these districts are shown in fig. 1, and also in most of the later maps.

Most of the previous general petrographic description is due to Dr. J. S. Flett, and the present investigation continues his work, extending it chiefly in a quantitative direction. I beg leave to extend my thanks to Dr. Herbert H. Thomas, by whose courtesy I have been enabled to examine and measure the slides from this district in the collection of the Geological Survey.

II. Mineral Composition of the Granite.

Dr. A. Johannsen's[1] areal method of micrometric measurement was chosen for the work in hand, partly because it adapts itself especially to the analysis of the coarse-grained rocks, and partly because it offers advantages arising from the concentrated study of a single field at a time. Measurement was carried out under a 1-inch objective for all slides, for this power enables the amount of accessories to be estimated, without at the same time unduly limiting the field. The scale of measurement should be determined, for the actual areas of the minerals present are sometimes of use in estimating the distribution of inclusions, etc. The mean specific gravities of minerals, as given by Dr. H. A. Miers,[2] were

[1] Journal of Geology, vol. xxvii (1919) pp. 276–85.
[2] 'Mineralogy' 1902, pp. 556–61.

used in the conversion of the determined volumes into weights. The reduction of averages and routine calculations were made on a 10-inch slide-rule.

Now, in all work of this kind the problem of the effects of sampling is prominent; but here the problem is complicated in several ways. We are studying the point-to-point variation of a granite, which, though by no means uniform, presents no startling quantitative differences, and yet is at the same time coarse-

grained, and, therefore, highly susceptible to the vagaries of sampling. Moreover, if five minerals are present, one only may be really increasing or decreasing, while the others, maintaining their proportions relatively one to the other, yet as a whole decrease or increase antipathetically with the varying constituent. Some criterion is consequently necessary to separate significant variations from these effects combined with those of sampling. Furthermore, when many localities are examined, considerations of time and expense impose a limit to the number of slides available from

each locality, and some means of evaluating the observations is the more urgent.

To afford material for a statistical study of the problem of sampling, eight slides were taken from a granite of Dyer's Quarry, Meledor (No. 48). Seven of these were cut from two specimens, selected at a distance of about 40 feet from the contact of granite and slate. An eighth slide was obtained from the Geological Survey, and is, therefore, independently selected. The volumes of the minerals obtained by measurement are recorded in Table I, of which the lowest row gives the number of fields measured as an indication of the area of the slides. All locality averages stated hereafter are weighted according to the areas of the slides involved; but the general averages for whole districts are the unweighted means of the localities.

TABLE I.—PERCENTAGE MINERAL COMPOSITION BY VOLUME OF EIGHT SLIDES FROM DYER'S QUARRY, MELEDOR (NO. 48).

Mineral.	A.	B.	C.	D.	E.	F.	G.	H.
Quartz	33·7	28·8	36·2	27·8	26·5	34·0	26·7	44·5
Orthoclase......	35·3	49·0	31·5	45·0	45·3	42·1	49·9	28·6
Plagioclase ...	20·6	11·7	13·7	18·5	19·4	14·9	13·7	15·1
Biotite	3·7	3·2	7·7	2·9	3·2	4·7	3·2	5·0
Muscovite	n. f.	0·3	0·2	0·1	n. f.	0·2	n. f.	n. f.
Apatite	n. f.	n. f.	1·2	tr.	n. f.	n. f.	n. f.	0·1
Magnetite ...	0·1	0·2	tr.	tr.	n. f.	tr.	tr.	tr.
Tourmaline ...	4·6	3·6	5·7	3·6	2·5	1·8	3·7	3·3
Topaz.	1·3	3·0	3·8	2·1	2·9	2·2	2·4	3·3
Fluorite.........	0·7	0·2	n. f.	n. f.	0·2	0·1	0·4	0·1
No. of Fields ...	14	18	18	20	13	20	16	14

The addition of the eighth slide hardly affected the mean appreciably, and the final mean of the eight slides may be considered as giving a close approximation to the true composition of the rock. Averages were now calculated for all combinations of the slides, taken one at a time; two at a time; and so on, up to seven at a time. In this way suites were obtained, each containing large numbers of averages, involving the worst conditions of sampling in the material. The criterion of sampling adopted was the standard deviation (that is, the error of the mean square). Accordingly, the standard deviations of the minerals of each suite (that is, for one, two, three, etc. slides) were calculated; these will be found in Table II, and are plotted in fig. 3, p. 550.

Fig. 3.—*Curves showing the effect of sampling by slides from granite, Dyer's Quarry, Meledor.*

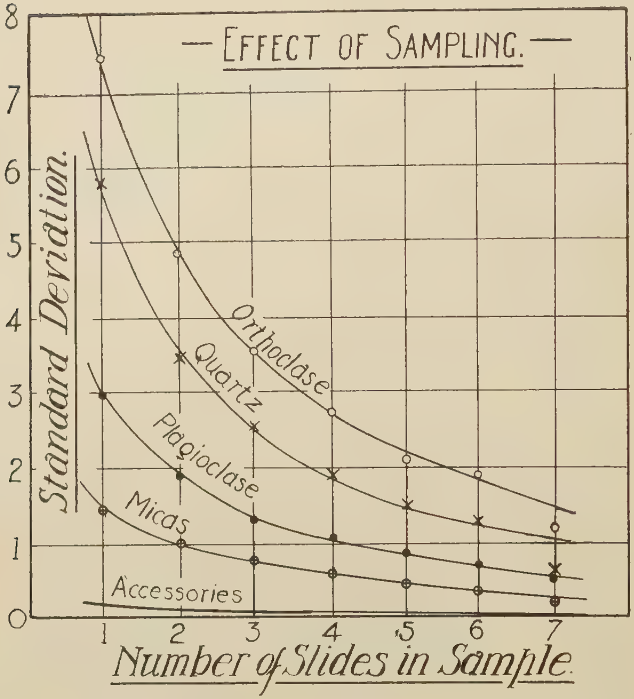


TABLE II.—STANDARD DEVIATIONS OF MINERAL PERCENTAGES CALCULATED FROM THE VOLUMES IN TABLE I (p. 549).

	Mean.	*Standard deviation (with reference to mean).*						
Number of slides	8	1	2	3	4	5	6	7
Mineral.								
Quartz	32·2	5·8	3·5	2·6	1·9	1·5	1·3	0·6
Orthoclase.........	41·1	7·5	4·9	3·5	2·8	2·0	1·9	1·2
Plagioclase	15·8	3·0	1·9	1·6	1·0	0·9	0·7	0·4
Mica	4·3	1·5	1·0	0·8	0·6	0·4	0·36	0·26
Accessories	0·2	0·1						

These curves bring out two points of general interest. Where one slide only is available the standard deviation is naturally large, but the curve falls so rapidly that, when three slides are taken, the standard deviation is reduced by one half. Thereafter the curves flatten, and for practical purposes the standard deviation becomes sensibly constant. Again, it will be noticed that the standard deviations of such constituents as orthoclase, present in large crystals and irregularly distributed in the slides, are much greater than those for plagioclase or mica present in smaller, more uniformly distributed units. It follows that variations in the last-named minerals are more significant than greater differences in the first-named, especially when the number of slides is small; and, by consideration of the smaller units, an estimate may sometimes be made of the value of a single slide, when nothing could be inferred from the larger units.

The usual convention (based on the consideration that the chances are against the effect of sampling being greater than three times the standard deviation) is to take all variations lying within a range of three times the standard deviation as due to sampling, while deviations beyond this range may be regarded as significant.

TABLE III.—VOLUME DIFFERENCES BETWEEN LOCALITIES 48 *a* (CONTACT) AND 48 (40 FEET FROM CONTACT), DYER'S QUARRY, MELEDOR.

Mineral.	*Difference.*	*Standard deviation* × 3.
Quartz	+4·9	7·8
Orthoclase	−2·2	10·8
Plagioclase	−2·1	4·5
Coloured mica	−2·0	2·4
Colourless mica	+3·3	2·4
Tourmaline	−0·3	1·8
Topaz	−2·2	1·2
Fluorite	+0·6	0·3

For example, if there be a difference of 10 per cent. between the amounts of quartz in two localities, and if the amounts rest on three slides; then, since 10 per cent. is greater than 3 × 2·6 (standard deviation for quartz in three slides), the difference may be regarded as due to some other cause than sampling.

A practical illustration of the application of this criterion will be found in comparing the composition of the main rock at Dyer's Quarry with that at the contact (Nos. 48 & 48 *a*). Three slides of the contact-rock were available, including one from the Geological Survey. In Table III the differences between the percentages for localities Nos. 48 and 48 *a* are set forth in the first column, and the second contains the standard deviations (when three slides are used) multiplied by 3. Now, is there any significant quantitative difference between the granite at the contact and that 40 feet away? The table at once shows that differences in the amounts of quartz, orthoclase, plagioclase, and biotite lie well within the limits of sampling. Muscovite, topaz, and fluorite, however, show changes lying well beyond these limits, and may be considered as significant. In approaching the contact at this point there has been an increase in muscovite and fluorite, but a decrease in topaz.

Space does not permit of each case being argued separately. But it will be understood that variations were compared with standard deviations in the drawing of boundary-lines, etc. Furthermore, since rock-changes proceed upon some definite plan, smaller variations than the limits of sampling may become significant when each locality does n o t s t a n d a l o n e. If the variations from point to point are merely due to the sampling, then their distribution over the area will be haphazard. If, on the other hand, they group themselves in a definite way, it is clear that such arrangement could not be regarded as caused by sampling, but must be sought for in real differences in the material. In such an event, the standard deviation is a test which greatly assists the evaluation of exceptions to the general grouping.

Table IV (facing this page) sets forth the results of the measurements, reduced to percentages by weight, for the fifty localities within the main granite-mass. The difference between the weights and volumes involves only a small correction, and the volumes are omitted in order to save space. There are several species of mica present, but they are grouped here as 'coloured' and 'colourless.' The nature and distribution of the types will be considered below.

The porphyritic character of the granite can be dealt with where large surfaces suitable for measurement are available, as in the Gready Quarries. Nevertheless, some difficulty exists even here, for the phenocrysts and ground-mass crystals of orthoclase are not sharply separated as they are, for example, at Shap. There appears to be a series in which every size is present from the largest phenocryst to the normal ground-mass grain. It is, therefore, difficult to make sure that slides represent ground-mass only.

This question of the porphyritic orthoclase chiefly affects the Luxullyan area. The amount of phenocrystic orthoclase was measured at Golden Point (No. 5) and found to be 18·3 per cent.; and at Gready (No. 4) and found to be 19·8 per cent. Round figures of 18 and 20 per cent. respectively were taken, and the compositions given in Table IV for these localities have been corrected for this amount. It is certain that Helman Tor (No. 6) should also be corrected. The phenocrysts here seem smaller, and less numerous; but, on the scattered lichen-covered boulders, satisfactory measurements could not be made, and no correction has been applied. Towards the margins in this area the phenocrysts either disappear or are small in amount, but easterly exposures are neither numerous nor good. This district, therefore, was sampled by one section, along which good exposures were available. The results of this section will probably give a better result for the bulk composition of the area, than if a number of specimens from unsatisfactory localities had been included.

In the other areas the porphyritic orthoclase is less troublesome. The phenocrysts are much smaller and generally quite sporadic. At Foxholes a measurement indicated about 1½ per cent.; another at Yondertown not more than 5 per cent. These figures are well within the limits of slide-sampling, and corrections were not made.

Table IV.—Mineral Composition at Selected Localities: Weight per cent.

Reference Number.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
Localities.	Carnears Wood.	North Hill Wood.	Rock Mill, Luxullyan Valley.	Gready.	Golden Point Quarry.	Helman Tor.	Carna, Menadue.	Criggan.	Hallow Farm.	Lower Woon.	Goonbarrow.	Tresayes Downs.	Carbis Common.
Number of slides	2	2	1	5	3	2	2	1	1	1	1	1	1
Quartz	24·9	37·7	12·5	23·6	23·9	35·0	31·3	35·8	25·6	36·4	35·3	47·9	11·7
Orthoclase	36·0	30·5	27·0	48·2	52·4	31·9	35·5	33·5	31·9	32·8	25·5	16·7	27·6
Plagioclase	17·5	22·7	14·4	14·6	14·7	13·9	18·8	11·4	20·1	22·6	28·4	18·5	17·2
Coloured micas	15·0	2·3	7·1	6·5	5·5	12·4	9·4	11·0	14·1	5·5	0·0	8·5	7·4
Colourless micas	4·9	2·9	5·1	2·6	1·1	4·3	3·1	4·8	3·3	0·2	9·0	2·9	0·9
Iron-ores	tr.	0·6	0·4	0·4	0·4	0·6	0·2	0·4	0·2	0·2	tr.	0·2	0·1
Apatite	0·2	0·1	0·8	0·4	0·4	0·5	0·1	0·1	0·9	0·1	1·6	0·2	0·1
Cordierite (& pinite)	1·1	1·1	1·6	2·6	0·7	0·2	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.
Andalusite	n. f.	n. f.	n. f.	0·1	0·2	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.
Tourmaline	n. f.	2·1	1·1	1·0	0·7	0·7	1·6	1·9	3·3	1·4	n. f.	4·0	3·6
Topaz	0·4	n. f.	n. f.	n. f.	n. f.	0·5	n. f.	1·1	0·6	0·8	0·2	1·1	1·4
Fluorite	n. f.	n. f.	n. f.	tr.	n. f.	n. f.	n. f.	n. f.	tr.	n. f.	n. f.	n. f.	n. f.
Number of haloes	19	22	5	42	36	15	3	7	7	9	n. d.	8	7
Quartz-grain mms.	2·0	2·5	2·5	3·0	2·5	2·0	0·75	1·2	1·0	1·5	n. d.	·5 1·0	1·0

Reference Number.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.
Localities.	Carnsmerry.	Stenalees.	Bunny Mine.	Hensbarrow Beacon.	Do. (summit).	Yondertown.	Barbelingey.	Carclaze Downs.	Vivian's Quarry, Pentruff.	Carn Grey, Pentruff.	Hill Farm North, Menacuddle.	Hill Farm South, Menacuddle.	Trenance Viaduct, East.	Do.
Number of slides	1	2	1	1	2	1	1	1	2	4	2	2	1	2
Quartz	34·8	19·7	30·7	25·2	28·1	35·6	27·1	36·4	37·7	34·4	35·4	27·5	39·6	33·3
Orthoclase	35·8	45·1	36·4	40·0	31·6	34·4	42·4	29·8	28·1	35·0	37·4	41·4	31·0	38·1
Plagioclase	17·9	30·2	25·0	18·0	23·0	13·1	25·6	16·4	15·6	18·1	15·1	17·6	14·7	15·9
Coloured micas	5·6	1·2	1·1	12·2	4·1	8·5	0·0	10·7	8·9	4·6	4·1	6·8	0·0	7·0
Colourless micas	4·4	3·2	1·0	0·0	5·6	0·0	3·5	1·6	5·2	2·9	2·4	2·3	10·7	0·0
Iron-ores	0·6	0·4	0·2	0·2	0·2	0·4	0·2	0·4	0·8	0·4	0·1	0·5	0·4	0·6
Apatite	0·1	tr.	n. f.	tr.	0·4	0·1	n. f.	n. f.	0·2	0·2	0·2	0·3	0·1	0·1
Cordierite (& pinite)	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.	0·4	2·6	1·1	n. f.	n. f.	0·1
Andalusite	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.
Tourmaline	0·8	0·2	2·2	n. f.	0·1	0·8	1·1	4·5	3·1	2·8	1·4	3·6	3·0	4·5
Topaz	n. f.	n. f.	3·3	4·4	6·0	7·1	n. f.	0·2	n. f.	n. f.	2·8	n. f.	n. f.	0·3
Fluorite	n. f.	n. f.	0·1	n. f.	n. f.	n. f.	0·1	n. f.	tr.	tr.	n. f.	n. f.	0·5	0·1
Number of haloes	32	0	4	1	11	1	0	5	2	24	3	0	0	2
Quartz-grain mms.	1·0	1·0	0·75	0·3 1·0	0·2 1·0	0·5 1·5	1·3	1·5	0·5 1·0	1·5	1·5	0·5 1·5	1·5	0·2 1·5

Reference Number.	28.	29.	30.	31.	32.	33.	34.	35.	36.	37.	38.	39.	40.
Localities.	Trenance Viaduct, West.	Greensplat.	Near Dubber's Works.	Tregarden, Longstone Downs.	St. Mewan Beacon.	Watch Hill.	Foxholes.	St. Stephen's Beacon.	North-west of St. Stephen's.	[illegible] Mill.	Wheal [illegible]	Nanpean.	Restowrack Downs.
Number of slides	2	1	2	1	2	1	1	1	1	8	1	2	2
Quartz	34·6	28·8	34·0	30·5	26·2	36·9	35·3	21·3	28·7	33·1	[illegible]	35·4	[illegible]
Orthoclase	32·2	42·7	26·4	39·5	36·5	32·1	30·3	44·7	29·3	[illegible]	[illegible]	28·5	[illegible]
Plagioclase	17·4	18·3	17·3	14·1	29·0	16·4	15·5	20·3	24·1	17·4	26·7	[illegible]	14·4
Coloured micas	9·3	4·6	4·3	0·0	4·8	7·6	11·1	0·0	0·0	0·0	[illegible]	[illegible]	[illegible]
Colourless micas	0·0	1·1	14·7	7·7	1·1	0·1	0·3	12·1	[illegible]	11·2	[illegible]	11·3	12·3
Iron-ores	0·3	0·2	0·6	0·8	tr.	0·3	0·4	n. f.	0·2	0·2	0·2	tr.	[illegible]
Apatite	tr.	tr.	0·4	tr.	0·1	tr.	n. f.	0·4	0·4	0·2	0·1	0·1	2·5
Cordierite (& pinite)	n. f.	0·4	n. f.	0·7	n. f.	n. f.	n. f.	n. f.	0·1	n. f.	0·4	n. f.	1·1
Andalusite	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.
Tourmaline	n. f.	1·9	0·4	7·0	2·3	2·1	2·3	0·1	7·4	0·6	n. f.	n. f.	n. f.
Topaz	6·2	2·0	n. f.	n. f.	n. f.	4·2	4·8	0·8	1·4	2·8	1·5	n. f.	2·7
Fluorite	tr.	n. f.	1·9	n. f.	n. f.	n. f.	n. f.	0·3	0·5	1·6	0·2	2·1	2·5
Number of haloes	3	0	1	0	2	24	12	0	n. d.	0	0	0	0
Quartz-grain mms.	0·5 1·5	0·75	1·0	0·5 1·0	0·5	1·0	1·0	0·75	n. d.	1·5	n. d.	1·5	1·5

Reference Number.	41.	42.	43.	44.	45.	46.	47.	48.	48a.	49.	50.
Localities.	Purple Quarry.	[illegible]	Little Treviscoe.	Great Treviscoe.	[illegible]	Hill Head, Trethosa.	[illegible]	Dyer's, Meledor.	Do. [illegible]	[illegible]	[illegible]
Number of slides	1	1	1	1	2	1	1	8	3	1	3
Quartz	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	47·9	25·6
Orthoclase	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Plagioclase	[illegible]	[illegible]	[illegible]	[illegible]	21·3	[illegible]	17·0	15·7	13·7	[illegible]	[illegible]
Coloured micas	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1·7	[illegible]	1·1	[illegible]
Colourless micas	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0·1	[illegible]	[illegible]	[illegible]
Iron-ores	0·1	0·1	0·1	[illegible]	[illegible]	tr.	0·1	0·1	[illegible]	[illegible]	[illegible]
Apatite	[illegible]	0·2	tr.	tr.	[illegible]	0·5	tr.	0·2	[illegible]	1·1	[illegible]
Cordierite (& pinite)	n. f.	n. f.	n. f.	n. f.	0·2	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.
Andalusite	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.	n. f.
Tourmaline	tr.	0·4	0·2	n. f.	0·3	0·2	3·7	4·2	3·8	3·5	3·8
Topaz	n. f.	n. f.	0·4	5·1	2·2	2·0	n. f.	3·4	0·5	n. f.	0·2
Fluorite	1·2	1·3	n. f.	n. f.	2·2	4·3	1·0	0·2	[illegible]	n. f.	n. f.
Number of haloes	n. d.	0	1	n. d.	6	0	n. d.	5	n. d.	1	13
Quartz-grain mms.	n. d.	1·5	1·5	n. d.	1·5	1·5	n. d.	0·75	n. d.	0·2 2·0	0·5 2·0

Near the margins bands of closely-packed, parallel phenocrysts sometimes occur, chiefly in the district near Menacuddle. A good exposure on the east side of Trenance Viaduct showed that such bands were thin. They were accordingly avoided in sampling, as there their total effect on the bulk composition is small, and single samples would disturb the result. Finally, there are porphyritic rocks in which the grain of the phenocrysts is the general grain of the rock, and these porphyritic elements are embedded in a small amount of very fine ground-mass. Careful selection of slides from such rocks ensures good sampling, and they give rise to no uncertainty.

III. The Minerals and their Distribution.

The most advantageous way of presenting the distribution of mineral quantities and their peculiarities is by a series of maps. Considering the coarse-grained character of the rock and the fluctuations of sampling, attempts at fine contouring were not helpful; but the device described below is a rapid method for detecting the existence of definite grouping. Each amount was compared with the arithmetic mean for the whole series (col. I, Table V, p. 554). If in excess of the mean a *plus* sign, and if in defect a *minus* sign, was plotted at the locality. Boundaries were then drawn enclosing the '*plus*' quantities. These boundaries are shown by heavy chain-dotted lines in the maps, and the *plus* sign indicates the side on which the quantities are greater than the mean. Exceptions to the groupings are shown by small circles instead of dots. Such groupings of value with respect to the general average will be designated groupings of the first order.

Quartz.—Throughout the whole district the quartz possesses the characters usually met with in granites, but in places a few peculiarities are developed. Quite large patches of quartz, when present, in most cases are resolved microscopically into aggregates of smaller crystals. Occasionally, however, single crystals are found sometimes so much larger than the general grain as to merit the term 'phenocryst'.

Slight strain-shadows are usual, and only absent from grains enclosed in orthoclase. In the Luxullyan area frequently, and elsewhere occasionally, the quartz may present idiomorphic outlines to the orthoclase. Cracks in the quartz are, as a rule, quite irregular; but some examples exhibit a pattern, with a crudely rectangular arrangement, doubtless due to the imperfect rhombohedral cleavage. Examples were seen at Gready and Tregargus Mill, but the feature does not appear to be confined to special localities.

The larger inclusions in quartz may consist of any other rock-mineral, while the bulk of the more minute inclusions is made up of fluid-filled cavities (with bubbles, etc.). These may be so small as to be almost irresolvable under high power, but may be as

large as 0·02 mm. in longest diameter. The larger inclusion-cavities do not appear to favour definite areas. In the Luxullyan area rutile-needles were occasionally met with, though not detected with certainty elsewhere. More numerous are minute bipyramids of zircon, commonest towards the east, but present in most localities. Various modes of arrangement of the minute inclusions are found. Generally they are linear, as in most granitic quartz. In some areas, especially St. Stephen's, they are present uniformly distributed as dust. More rarely, they are segregated into wide dense bands, which divide the quartz into irregular polygons.

Table V.—Mean Mineral Composition of Granites. (Weight per cent.)

Mineral.	I	II	III	IV	V	VI	VII
Quartz	32·6	31·7	33·8	29·9	31·9	24·4	22·6
Orthoclase	34·5	37·3	34·1	33·7	10·2	36·2	19·7
Microcline	tr.	—	—	—	20·5	—	—
Plagioclase	19·2	16·5	18·5	22·0	20·2	33·6	46·8
Biotite	4·7 (Biotite + Lithionite)	7·6	—	—	11·9	5·8	5·8
Lithionite			8·8	—	—	—	—
Muscovite	4·5	3·4	—	9·7	4·7	—	—
Hornblende	—	—	—	—	—	—	2·9
Magnetite	0·3	0·4	0·3	0·1	0·4	—	2·2
Apatite	0·3	0·4	0·3	0·4	0·2	—	tr.
Cordierite	0·3	1·4	0·1	0·2	—	—	—
Andalusite	tr.	tr.	—	—	—	—	—
Tourmaline	1·8	1·2	2·4	0·8	—	—	—
Topaz	1·4	0·1	1·6	1·7	—	—	—
Fluorite	0·4	tr.	0·1	1·5	—	—	—

I = St. Austell Granite; mean of all localities and types.
II = St. Austell Granite; mean of biotite-muscovite type.
III = St. Austell Granite; mean of lithionite type.
IV = St. Austell Granite; mean of gilbertite type (petunzite).
V = Alkali-granite, Rubislaw, Aberdeen.
VI = Biotite-granite, Wasdale Head, Shap (A. Holmes, 'Petrographic Methods & Calculations' 1921, pp. 394–95).
VII = Hornblende-granite, Mountsorrel.

The number of inclusions varies enormously. No numerical estimate was made; but, speaking generally, the quartz is most crowded with them in the St. Stephen's area, and least so in the Luxullyan area.

The mean percentage weight of quartz for the whole granite-

mass is 32·6. If boundary-lines are now drawn between those localities with quartz in excess of this amount and those with values below it, it will be found that the quantities are not distributed in haphazard fashion, but fall into very definite groupings shown in the map, fig. 2 (p. 548). The boundaries are drawn in thick chain-dotted lines, and there are only four exceptional places. Of these Nos. 19, 25, and 50 cannot be regarded as real exceptions, since the differences are well within the limits of sampling; while No. 6 on Helman Tor would probably conform if allowance had been made for the presence of phenocrysts of orthoclase.

Now, none of the areas so delineated show any relation to the boundaries of the granite-outcrop. The mass is divided into a series of broad belts, exhibiting a rough parallelism with axes directed more or less west of north. There are three positive areas alternating with negative areas. The first positive zone occupies the Retew area, the second lies at the western end of the Hensbarrow area, while the third occupies the eastern end of this area and the south-western part of the Luxullyan area. The whole of the St. Stephen's area is a negative belt.

Orthoclase.—Several kinds of monoclinic felspar are probably present in the granite; but the dominant type is perthite, of which the large phenocrysts are formed. In the Luxullyan area the albite patches are relatively large, and the albite lamellæ may be distinguished without difficulty. In the Hensbarrow district, where not obscured by alteration, the albite patches are finer, while in the St. Stephen's area the orthoclase often appears to be more homogeneous. The orthoclase includes and moulds most of the other minerals, and a long period of crystallization is indicated.

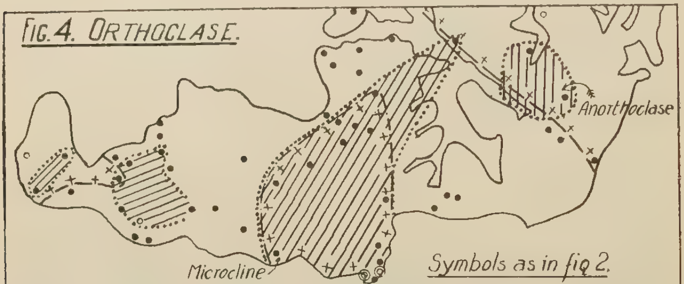
Greenish anorthoclase was discovered in the granite of Gready by Mr. T. C. F. Hall.[1] I have not found this mineral in specimens from other quarries. At St. Mewan Beacon, however, associated with the perthite is a felspar showing the nearest approach to the cross-hatching of microcline that I have found in the area. The sections of this mineral are much more irregular in shape than the perthite, but the cross-hatching is of finer grain and less regular than that in good microcline, although more so than that in the anorthoclase at Gready.

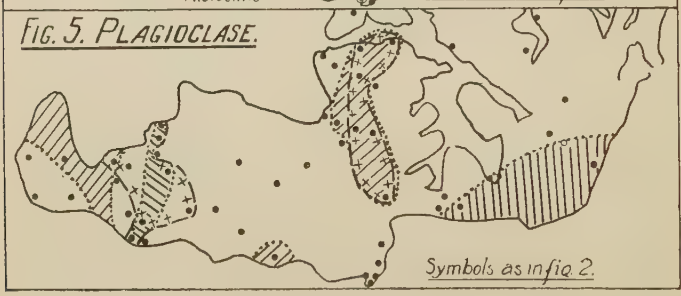
The orthoclase, even apart from surface-weathered specimens, has always suffered some degree of alteration. In the Luxullyan area this does not amount to more than a slight cloudiness. In the Hensbarrow area, on the other hand, the orthoclase is almost opaque by ordinary light, and snow-white by reflected light, on account of extensive alteration. In the St. Stephen's area the orthoclase may sometimes be fairly fresh: it is often, however, extensively altered, as Dr. Flett noted, sometimes to kaolin, but more

[1] 'Report of an Excursion to the St. Austell District (Cornwall)' Proc. Geol. Assoc. vol. xxvi (1915) p. 40 & pl. v, fig. A.

characteristically perhaps to white mica. Often whole areas of orthoclase are replaced by scaly aggregates of muscovite.

Orthoclase always forms the largest crystals present, and it is also the dominant mineral in the general average, amounting to 34·5 per cent. In the map (fig. 4) it is seen to group itself in a regular manner on application of the method already used in the case of quartz. Exceptions over half of 1 per cent. are indeed somewhat more numerous, but in no case does the variation exceed the probable limit of sampling. In general, the belts for quartz and orthoclase coincide: the negative quartz-areas being also positive orthoclase-areas. There is one exception, for the western negative orthoclase zone is extended over the whole of the St. Stephen's area, and this area is, therefore, a zone where both quartz and orthoclase fall below the general average.





Plagioclase.—Complete examination of the slices reveals the presence of two rather sharply contrasted types of plagioclase. One of these is confined to the Luxullyan area. It occurs in large crystals, strongly zoned, and centrally altered. The refractive index of all the plagioclase is less than that of the ϵ-ray of quartz; but in some zoned crystals, situated at the edge of a slice, the centres had refractive indices higher than Canada balsam. Where good sections parallel to (010) were present, the extinction at the centre was either nearly 0 or a small negative angle, but increased to a large positive value at the extreme outside zone. The maximum extinction-angles of the albite lamellæ confirmed these results, indicating that the centres have a composition nearly that

of andesine, varying outwards to that of pure albite. The bulk composition of these zoned felspars is probably that of a somewhat acid oligoclase.

The second type of plagioclase occupies the remainder of the granite-mass. It has a mean grain considerably smaller than the Luxullyan plagioclase; it is not zoned, and, when altered, the products are distributed uniformly. The extinction-angles are greater, and on the whole increase westwards. A felspar containing but a very small proportion of lime is indicated, and in the St. Stephen's area angles approaching those of pure albite were frequently obtained.

The chief alteration-product appears to be mica. The Luxullyan crystals have quite fresh margins, and the mica-flakes can be detected in abundance in the central zone of intense alteration. In the Hensbarrow area the plagioclase is generally cloudy, and mica-flakes appear parallel to the directions of cleavage; but the plagioclase is much less affected than the orthoclase of the area. In the St. Stephen's area the plagioclase is often very fresh, and, when it is altered, mica again plays a part.

Plagioclase amounts to 19·2 per cent. in the general average. After grouping the values on a map (fig. 5, p. 556) we find two zones in which plagioclase is above the average. The westernmost of these lies entirely within the St. Stephen's area, coinciding with a belt of low quartz, and with part of a belt of low orthoclase. The second zone forms a narrow elongated strip immediately east of Hensbarrow. At St. Mewan Beacon (No. 32) the variation is greater than the probable limits of sampling, and may be significant.

Micas.—The micas are, in some respects, the most interesting minerals. They have been tabulated in two classes—coloured and colourless—according to their appearance in thin section. There are at least four species present, which will now be described under the names biotite, lithionite, muscovite, and gilbertite. These varieties (as will be shown below) have a definite areal distribution.

In addition to their general characters, the apparent axial angle (2 E) was determined in all suitable sections, and on cleavage-flakes from the hand-specimens. The angles obtained were very variable, even in good basal sections among the same types of mica; but each type had a fairly characteristic range of values.

The biotite is confined to the Luxullyan area, with two exceptions: namely, Carnsmerry (No. 14) and St. Mewan Beacon (No. 32). The biotite has very strong absorption, a deep reddish-brown colour, and is crowded with pleochroic haloes. In every slide there are always some crystals partly chloritized. The apparent axial angle in the cleavage-flakes and sections varies from 12° up to 15°. In the absence of chemical evidence it is, of course, not denied that this mineral may be lithia-bearing: but its optical characters most closely resemble those of ordinary granitic biotite.

The lithionite type of mica is confined to the Hensbarrow

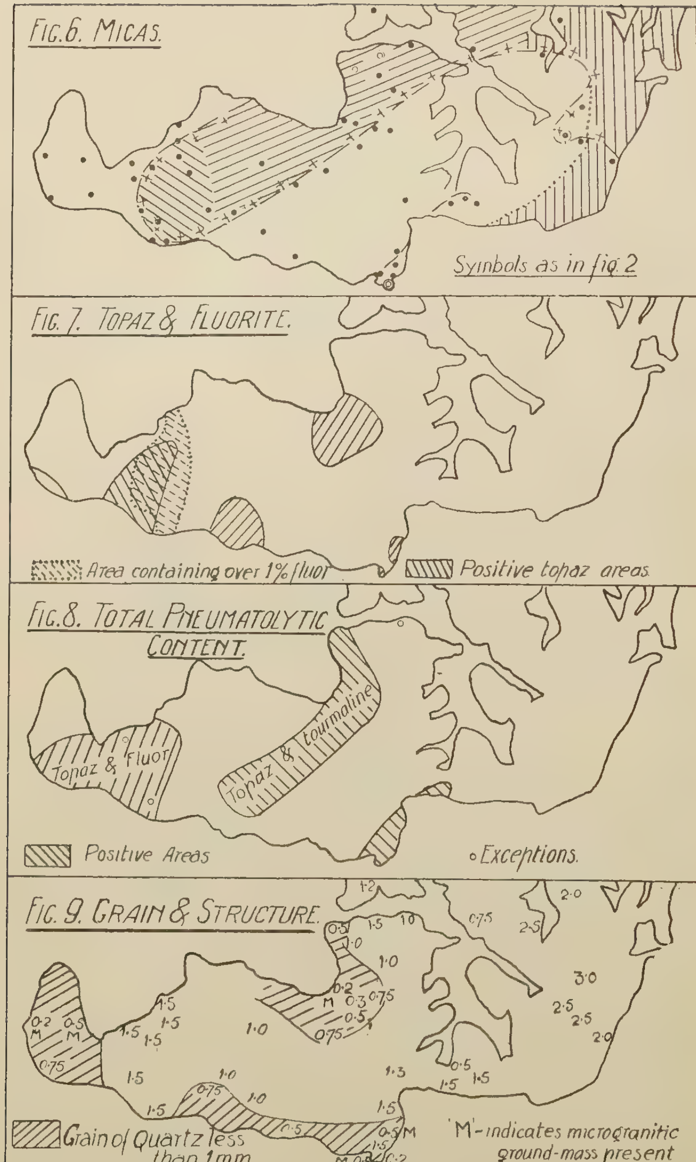


Fig. 6. Micas.
Symbols as in fig. 2
Fig. 7. Topaz & Fluorite.
Area containing over 1% fluor
Positive topaz areas
Fig. 8. Total Pneumatolytic Content.
Topaz & Fluor
Topaz & tourmaline
Positive Areas
Exceptions.
Fig. 9. Grain & Structure.
Grain of Quartz less than 1mm.
'M'-indicates microgranitic ground-mass present

and Retew areas. It is distinguished in general appearance from the biotite by a paler colour, with a reddish-yellow rather than reddish-brown tinge, passing at times into a pale yellow. Pleochroic haloes are less numerous, and, further, the lithionite, even in the most weathered surface-specimens, is never chloritized. The colour in thin section shows every gradation from examples with moderately deep tints to those that are completely colourless. Sometimes merely a faint flush is discernible as we rotate the polarizer, and in other cases the only signs of colour are pleochroic haloes and irregular pleochroic areas. The flakes may be bleached at the margins, or the colour may have a very patchy distribution. Some examples are clear and limpid, while others have a dirty or dusty appearance, whether because of minute inclusions or of some kind of alteration I was unable to determine. The apparent axial angle has a wide range of values, and appears to decrease with depth of colour. The more deeply coloured flakes give an angle of about 30°, which increases up to 54° in a variety colourless in thin section; while the pale varieties give angles between 40° and 46°. The angle of lithionite, according to Dana, is 50°.

The mica within the Hensbarrow area, except for small amounts of secondary muscovite, is to be regarded as of one kind. The distribution of the more deeply coloured types is not very regular, and all that can be said is that the pale and colourless varieties are more frequent near the margin: as, for example, at Hensbarrow Beacon (No. 18), or at Trenance Viaduct (Nos. 24 to 28).

True primary muscovite is practically confined to the Luxullyan area, where it is intergrown with the biotite. A little occurs associated with biotite at St. Mewan Beacon (No. 32), and also at the contact in Dyer's Quarry, Meledor.

The St. Stephen's area has a peculiar mica with silvery lustre determined by Dr. Flett as gilbertite. It is colourless, and in thin section no haloes were seen. This is partly, but not altogether, due to the colourless medium, for high-power examination showed that highly refractive inclusions were scarce. The apparent axial angle was small when compared with that of muscovite. In general most good cleavage-flakes gave values between 23° and 30°, but values as high as 45° were obtained in some flakes from Tregargus Mill.

The distribution of the types has already been considered, and, owing to their variety, the total quantity of mica present without regard to type has been plotted on the map (fig. 6, p. 558). On grouping the values in relation to the general average of 9·2 per cent., I discovered one large positive belt, stretching from the River Fal to Helman Tor, with two very small groups along the south-eastern margin of the granite-mass. Only one exception appears within these groups: namely, No. 27; but its divergence is not significant. Some relation to the boundary of the granite exists, and the mica-zones are differently orientated from, and cut across the belts of the minerals already mapped.

Attention has been drawn to fluctuations in the number of the

pleochroic haloes. In order to obtain a quantitative idea of the variation, I counted the numbers present in each slide, and, so as to facilitate comparisons, these were reduced to a common basis by expressing them as the number per square millimetre of biotite (or lithionite). The values obtained are given in Table IV (facing p. 552) as 'number of haloes'. As might be expected, the distribution is somewhat irregular. When mapped they show no relation to the mica-zones of fig. 6; nor any striking correspondence with depth of colour. They are most numerous in the Luxullyan area, where the biotite is often so crowded with them as to defy enumeration. On the whole, despite some high values, they decrease steadily westwards, being absent in the St. Stephen's area. In the Retew area they reappear with the lithionite, and are most numerous at Melangoose (No. 50).

Iron-ores.—These are mainly magnetite, with occasional red patches and stains of hæmatite. Very little pyrites was seen. In the Luxullyan area the magnetite is well shaped, and occurs in large grains mainly associated with aggregates of biotite. In other areas the grains are smaller, more widely distributed, and less regular in shape. The average percentage is 0·3, and, when the deviations from this are plotted, two high zones are found. One includes the whole of the Luxullyan area and some of the localities on the west, and the other is situated immediately west of Hensbarrow Beacon. The St. Stephen's and Retew areas are deficient in iron-ores.

Apatite.—Two varieties of apatite are present. There are the usual clear grains of prismatic habit, associated with biotite-aggregates in the Luxullyan area, and more commonly with plagioclase in the other areas. In the St. Stephen's area a more uncommon variety is met with: it occurs in comparatively large, irregularly shaped masses showing indications of a cleavage, and has a dusty appearance, or is almost opaque with inclusions. It appears to have crystallized, or rather to have finished crystallizing, at a somewhat late stage, since it may be found partly enveloping felspar. Its optical properties agree with apatite, but this determination was confirmed microchemically.

Apatite amounts to 0·3 per cent. in the general average, and the mapped values indicate two positive areas. One is a long narrow belt stretching north-eastwards from Restowrack (No. 40) to Molinnis (No. 9), lying entirely within the large positive mica-zone (fig. 6, p. 558). The other is a small zone in the centre of the Luxullyan area. Except for three isolated values, the remaining localities are below the average.

Contact-minerals.—Andalusite occurs sparingly in the Luxullyan area associated with the cordierite, and is described by Dr. Flett. Outside this area it is not found within the main mass. Andalusite is, however, abundant in the satellite mass

at St. Denis, where it occurs in small grains which are always pleochroic. Some cordierite is present, and this is apparently a new locality for andalusite,

Cordierite of the well-known habit now associated with this district is confined to the Luxullyan area. There is no fresh cordierite, nor any similar pseudomorphs, outside the limits chosen for this area; but it is present at every locality within the area. In the Hensbarrow area, however, there occur small six-sided or rectangular grains of cryptocrystalline micaceous material, resembling pinite from the Vosges and elsewhere. These pseudomorphs are not similar in shape to the topaz-grains, nor is the structure that of mica-replacements after topaz. These small pseudomorphs, therefore, have been somewhat doubtfully measured as 'cordierite'; but their amount is generally quite small.

Pneumatolytic minerals.—The tourmaline found in the slides has the characters and relations of the type generally believed to be original. There is, in addition, a little obviously secondary tourmaline, in the form of prussian-blue needles and grains. Colour-zoning is sometimes observed, either as different tints of the same colour, or occasionally as zones of brown and blue. The sequence of the bands follows no general law, and shows no rhythm. The crystals are rarely idiomorphic, and then only towards quartz. Prismatic sections, whether of primary prism or of secondary needles, always show a rough basal parting. When secondary tourmaline is replacing mica, this parting bears no relation to the direction of the mica-cleavage, nor is there any structure present, such as Mr. D. A. MacAlister observed at St. Agnes Head, representing it.[1] Haloes are often present in the tourmaline, but are far less numerous than in the associated coloured mica.

1·8 per cent. of tourmaline is present in the general average. It is distributed in belts similar to those of quartz and orthoclase. Primary tourmaline is totally absent from the St. Stephen's area, although there are a few occurrences of secondary needles. The Hensbarrow area is occupied by a positive belt; but in the Luxullyan area the tourmaline is generally below the average.

The percentage amount of topaz in the general average is 1·4. and its distribution presents a distinct relation to the granite-margin, for the positive groups are arranged as small festoons along the outcrop. However, there is not a complete marginal zone, for negative values occur in places along the margin (fig. 7, p. 558). In the Luxullyan area topaz is practically absent, but high values are found in all the other areas.

Fluorite, except in traces, is confined to the western part of the St. Austell granite, and in the general average amounts to 0·4 per cent. Now, all localities containing over 1 per cent. of fluorite, with the single exception of No. 30, are to be found within

[1] 'The Geology of the Country near Newquay' Mem. Geol. Surv. 1906, p. 38.

the boundaries of what I have defined as the St. Stephen's area (fig. 7, p. 558). In this district two types of rock are recognized in the china-stone quarries, one with, and one without fluorite; but the relative proportions of the two could not be determined. Most of the localities are represented by slides of both types; but, in slides of the 'purple' variety only, fluorite bulked often as largely as 7 per cent.

The fluorite is secondary, though it is not at all clear what mineral it replaces. Small grains are found in micas and felspars, sometimes in the heart of the crystals, sometimes at their edges, and often arranged along cleavages or other lines. Some 228 occurrences of the mineral were counted, and they were situated as follows:—99 cases in mica; 69 in orthoclase; 54 in plagioclase; and 6 cases in quartz. Each single 'host' crystal was counted as one occurrence, although it might contain a dozen grains of fluorite. It is not easy to see any chemical reasons for this order of selection. and the preference shown to mica may be merely due to its greater permeability.

Finally, the investigation of the first-order grouping of the sum of the pneumatolytic group of minerals shows two belts of high values (fig. 8, p. 558). One occupies adjacent parts of the Retew and St. Stephen's areas, and is mainly due to topaz and fluorite. The second is in the Hensbarrow area, stretching from Watch Hill to just above Hensbarrow Beacon, and is mainly topaz and tourmaline. Both these zones have a south-westerly and north-easterly trend, and possess this feature in common with the principal lodes and the china-clay pits.[1] It must be emphasized, however, that the tourmaline and topaz of these granite-belts are minerals of the primary crystallization, and thus we have an indication that the main lines of pneumatolytic activity were to some extent determined, even before the complete consolidation of the granite.

IV. Correlations among the Minerals.

At different times correlations have been suggested between such pairs of minerals as biotite and tourmaline, and one of the objects of this enquiry was to provide a body of data whereby these relations might be investigated and tested.

Quartz and felspars.—When values were plotted on the maps, a striking antipathy between quartz and orthoclase was noticed. Naturally, the principal minerals will fluctuate inversely one to the other, but there appeared to be something more than this. The high zones of orthoclase and quartz interdigitate so persistently, that a high correlation appeared evident. On this account the correlation-coefficient for these two minerals was calculated, with the following results:—

Correlation-coefficient	−0·69
Probable error of coefficient	0·05

[1] 'The Geology of the Country around Bodmin & St. Austell' Mem. Geol. Surv. 1909, map, p. 108.

Evidently, a high negative correlation does exist, and it follows that increase in orthoclase is accompanied by a corresponding decrease in quartz, and conversely.

Now, the two felspars might be expected to behave similarly with regard to quartz, and one would expect good correlation also between quartz and plagioclase. The following are the calculated results:—

Correlation-coefficient, quartz and plagioclase......	−0·26
Probable error of coefficient	0·09

There is, indeed, a small negative correlation; but, for some reason, the fluctuations of quartz are more dependent on those of orthoclase than on those of plagioclase.

Biotite and tourmaline.—The case of these two minerals is of especial interest, for it has been discussed wherever Cornish granites have been investigated. Mr MacAlister[1] held, at least for the granite of St. Agnes Head, that tourmaline actually replaces biotite. Dr. Flett[2] is more cautious in reviewing the matter in connexion with the St. Austell mass, and says:—

'It is evident that the schorl is a primary mineral to a large extent, and though it may represent biotite, it does not replace it in every case.'

First, dealing with the district as a whole and assuming that the pale gilbertite of the St. Stephen's area represents the lithionite elsewhere, the calculation gives:—

Correlation-coefficient...... +0·04; probable error...... 0·09.

There is, therefore, no correlation at all under these conditions. Secondly, excluding the gilbertite values of the St. Stephen's area, and taking into account only the coloured micas, we have the following result:—

Correlation-coefficient...... −0·2; probable error...... 0·09.

Consequently, a very small, but definite, negative correlation does exist between biotite and tourmaline; but the latter can only be regarded as representing the biotite to a very slight extent.

Topaz and andalusite.—The suggestion that the topaz of St. Austell is equivalent to the andalusite so common in other Cornish granites is due to Dr. Flett (*op. cit.* p. 58). The data of the present investigation go far to confirm it. Consider, first, the quantitative conditions as summarized in the following table:—

District.	*Cordierite.*	*Andalusite.*	*Topaz.*	*Totals.*
Luxullyan	1·4	tr.	0·1	1·5
Hensbarrow and Retew ...	0·1	n.f.	1·6	1·7
St. Stephen's	0·2	n.f.	1·7	1·9
St. Denis..........................	0·5	1·1	n.f.	1·6

[1] 'The Geology of the Country near Newquay' Mem. Geol. Surv. 1906, p. 38.

[2] 'The Geology of the Country around Bodmin & St. Austell' *Ibid*, 1909, p. 59.

It becomes evident that topaz only occurs in quantity when the minerals of the contact-group are practically absent. Moreover, the amounts of contact-minerals and the topaz closely correspond. It is clear, therefore, that negative correlation is practically perfect.

Secondly, it will be recalled that, in the primary grouping of the minerals on the map of the district, the distribution of topaz differed from that of other minerals in being clearly related to the margin of the granite. And, if the topaz is partly the result of assimilation of sediment, then we should naturally expect it to increase somewhat towards the margins of the mass. Consequently, on the whole, the topaz may be regarded as largely a contact-mineral representing the andalusite of other districts, as Dr. Flett maintained.

V. Structure and Grain.

When speaking of the 'grain' of a rock, it is far better to have some quantitative value in mind than to rely on such vague expressions as 'coarse' and 'fine' grain. In choosing such a measure it is necessary to decide whether all the minerals shall be measured, or one only. If all the minerals are taken into account, in what way are we to express the result? And, if one mineral is to be used, which is likely to give the most useful result? No accepted method seems to exist, but the matter is helped by Mr. J. A. Howe's[1] conclusion that, if one mineral is large, all the others tend to be so too. In order to see whether this statement could be applied to the rocks under investigation, the principal minerals in a few slides from different parts were measured. It was found that the mean diameters of quartz, orthoclase, and plagioclase generally did correspond, but that the size of mica-flakes remained more or less constant throughout.

In view of this result quartz was finally chosen as the mineral upon which to base measurements for the grain, because among the principal minerals it gives the nearest approach to an equidimensional unit. The following conditions were observed:—

(*a*) Where the quartz occurred in the aggregates described above (p. 553) the individual grains were measured (between crossed nicols), and not the size of the aggregates.

(*b*) The mean of the greatest and least diameters was taken.

(*c*) The measurements were tabulated and counted at millimetre-intervals: that is, all lying between 1 and 2 mm. were counted as 1·5 mm., and so on. For sizes less than 8 mm., however, smaller intervals were used.

(*d*) The interval, or grade, containing the greater number was adopted as the grain for the locality: in other words, the mode of the measurements was adopted, and not their arithmetical mean. The mode has many advantages for the purpose. First, a certain amount of time is saved by avoidance of routine calculations; secondly, the most numerous size is a better measure of grain than mean size; and, thirdly, if

[1] 'The Geology of Building-Stones' 1910, p. 49.

the rock is porphyritic with a ground-mass of finer grain, this fact is brought out at once by the frequency method (for two modes are shown on counting), whereas an arithmetical mean would conceal it. The quartz-grain so determined is tabulated for each locality in the bottom row of Table IV (facing p. 552) as 'grain in mm.'

When these values for the quartz-grain of the rock are mapped (fig. 9, p. 558), it becomes evident that the different areas have different characteristics. Specimens from the Luxullyan area show grain that may be more than twice the size of that noted elsewhere. Its general value is about 2·5 mm., but marginal specimens yield somewhat smaller values. In the Hensbarrow area the grain is more variable, and always much smaller. Its general value may be taken as 1 mm.; but, especially towards the margin of the granite-outcrop, it is still smaller. The St. Stephen's area differs from the others, for the grain is sensibly uniform throughout; the marginal specimens do not differ from the more central. The general value of the quartz-grain in this area may be taken as 1·5 mm. The grain in the Retew area has a low value, and is about 0·5 mm. The grain, then, is coarser in the central parts, and finer towards the margin of the granite-mass.

Several types of structure are to be distinguished. There is the type which has been conveniently called 'granite-porphyry', found in the Luxullyan area, with large perthite-phenocrysts and a coarse hypidiomorphic ground-mass. Secondly, we note the usual granitic structure with small sporadic phenocrysts, characterizing the larger portion of the remaining areas. In addition to these, and always marginal, appears a porphyritic rock with a microgranitic ground-mass: as, for example, at Chytane, Hensbarrow Beacon, and near Trenance Viaduct. The phenocrysts comprise all the minerals, and are of the same grain as is found in the central parts of the area; while the ground-mass, consisting chiefly of quartz and felspar, is much finer. Associated with this type in the Trenance district are thin bands made up almost exclusively of elongated perthite-phenocrysts, showing flow-structure, and generally, but not invariably, arranged parallel to the margin.

The order of separation of the minerals has been elucidated by Dr. Flett, and I have little to add to his notes (*op. cit.* p. 58). So far as the normal minerals are concerned, it is (1) iron-ores and apatite; (2) micas; (3) plagioclase; (4) orthoclase; and (5) quartz. The observer is, however, struck by the astonishing degree of overlap in the periods of crystallization of the minerals.

Dr. Flett also showed that the pneumatolytic minerals—tourmaline and topaz—were at least largely primary, and exhibited long periods of crystallization, beginning shortly after the biotite. The bulk of these minerals appears to me to have separated just before the main crystallization of quartz. Seven cases of idiomorphic tourmaline were noted, and of these three were idiomorphic to orthoclase and four towards quartz. Finally, the minerals of the contact-group commenced shortly after the micas.

Little difference in the order of separation can be detected between the different areas. The same order is general throughout the mass, except in the case of apatite, and, perhaps, zircon. In the St. Stephen's area the apatite occurs in large irregular grains, and is more abundant than is usual in granites. These plates are found moulding felspars, or gathered into irregular aggregates formed later than the felspars. Zircon does not appear to be so common in this area, and is oftenest found in quartz.

Slight strain-effects are shown in practically every slide. The quartz always has some strain-shadows, except, as stated above, when enclosed in orthoclase. In this case the host doubtless protected the inclusion from pressure. Moreover, quartz-grains in aggregates commonly have suture-structure developed. Secondary quartz, however, is always water-clear, and never shows these phenomena. Finally, mica-flakes are occasionally bent. It is difficult to estimate the strength of the strain-effects; but, by comparison of slides, the amount of strain appears to increase towards the margin and to be least in the Luxullyan area.

VI. The Rock-Types and their Distribution.

Earlier in this paper the granite-mass was divided into four areas, which had been found to correspond qualitatively and quantitatively to different rock-types. This will have been more or less apparent in the preceding discussion, and it is now necessary to consider these rock-types and their relations. The rocks have been primarily separated by means of the dominant types of mica present into (*a*) biotite-muscovite-granite, (*b*) lithionite-granite, and (*c*) gilbertite-granite. The mean composition of these types will be found in columns II, III, & IV respectively of Table V (p. 554).

(*a*) Biotite-muscovite-granite.—This type is characterized by a biotite, with deep red-brown colour, strong pleochroism, and small axial angle. It is somewhat chloritized, and always intergrown with muscovite. In the main granite-mass this type is confined chiefly to the Luxullyan area. The apatite occurs in small, clear, idiomorphic grains. The plagioclase is an acid oligoclase in large strongly-zoned crystals with intensely altered centres, while the perthite is fresh. Brown tourmaline is present in some abundance, but there are only traces of topaz and fluorite. Contact-minerals are represented by abundant cordierite, associated with a little andalusite. The rock is coarse-grained, coarsely porphyritic, and is noteworthy for crowded pleochroic haloes around zircons enclosed in the biotite and, to a less extent, in the tourmaline.

Besides the Luxullyan rock there are two very small areas of biotite-granite within the Hensbarrow area: namely, at St. Mewan Beacon and Carnsmerry. These rocks are of finer grain and practically non-porphyritic.

(*b*) Lithionite-granite.—If we except a little secondary muscovite, the only mica present is pale lithionite. In thin section, its colour varies from a medium reddish-brown to colourless. The apparent axial angle is variable and generally large, but often much smaller, approaching that of the biotites. Marginal bleaching occurs, but the mineral is never chloritized, while the pleochroic haloes are much less numerous than in the biotite of the Luxullyan area. The microperthite is altered. The plagioclase has extinction-angles indicating a composition not far removed from albite, but with some content of lime-felspar. It is never zoned. Topaz is abundant, especially near the granite margins, and brown tourmaline is present in most localities. Apatite occurs in small grains, often clear, but sometimes crowded with inclusions. It is found embedded in plagioclase rather than in biotite.

The whole of the Hensbarrow and Retew areas are occupied by this type, and the rock exposed on Belowda Beacon is similar. The grain is of medium size, passing into more finely granular, and even into microgranitic types towards the margins.

The granite of Hensbarrow Beacon itself has been mapped by the officers of the Geological Survey as a separate fine-grained intrusion, analogous to the fine-grained later intrusions in other Cornish granites. They were unable to trace the boundaries exactly. My further examination of the locality reveals a rock that does not differ quantitatively or qualitatively from those of immediately neighbouring localities, but which (in grain) gradually passes into that of the central rock. Moreover, unlike the fine-grained intrusions of (for example) Carmenellis, it occupies a marginal situation, and is similar to other marginal types met with near Trenance and elsewhere within this area. I, therefore, consider it to be a fine-grained marginal facies.

(*c*) Gilbertite-granite.—This type is found between the boundaries which I have laid down as defining the St. Stephen's area, and which practically coincide with Mr. J. A. Howe's limits for the occurrence of 'china-stone'.[1] This granite is, in fact, the china-stone rock for which J. H. Collins proposed the name of 'petuntzyte'.[2] The mica exhibits the microscopic characters of gilbertite, is colourless but strongly absorptive in thin section, and has a smaller apparent axial angle than muscovite. The orthoclase is perthite, but often considerably altered. The plagioclase gives the extinction-angles of pure albite—a determination confirmed by the mineral composition calculated from analysis (see below). The apatite occurs in large grains, is almost opaque with inclusions, and crystallized out at a relatively late stage. Fluorite in irregular grains has a mean value greater than 1 per cent. in all localities. Topaz is generally present, but primary tourmaline always absent.

[1] See map, fig. 2, 'Handbook to the Collection of Kaolin, &c.' Mem. Geol. Surv. 1914, p. 11.
[2] 'The Hensbarrow Granite District' Truro, 1878.

The rock is non-porphyritic, with a medium and uniform grain throughout. No pleochroic haloes were observed, and the highly-refracting mineral grains are rare in the mica.

Dr. W. Pollard has made a complete analysis of china-stone from Goonvean Quarry,[1] lying a little to the north-east of Trethosa (No. 46). A doubtful trace of zirconia and high values for phosphoric pentoxide and fluorine are reported, agreeing with the measured values for the minerals concerned. It is interesting to compare mineral composition calculated from this analysis with the measured data. The procedure for calculating 'normative' minerals has been to some extent departed from, so as to make calculation fit in more closely with minerals known to be present. The lime was allotted, as usual, to apatite and fluorite; excess fluorine was then calculated as topaz, and finally excess alumina was allotted to water as kaolinite. In other respects the 'normative' procedure was followed, and the results are tabulated below:—

Quartz	31·3
Orthoclase	31·0
Albite	25·2
Anorthite	0·0
Apatite	1·3
Fluorite	2·6
Topaz	1·2
Kaolinite	5·9
Corundum	0·5
Other normative minerals	1·1
Total	100·1

The high values for apatite, fluorite, and topaz agree well when compared with the values for neighbouring places in Table IV (facing p. 552). It is noticed that, after these allotments have been made, no lime is available for the formation of anorthite, and this is in agreement with microscopic determinations. With regard to the principal minerals, quartz is slightly too high, orthoclase too low, and albite about correct for the position of the sample on the map. It must be remembered, however, that the orthoclase is evidently somewhat altered, and some material must have been removed; a little albite must be transferred to orthoclase to form perthite, and some orthoclase (or the kaolin) to form gilbertite. If these adjustments could be made, it appears likely that the sample would fit into its place within the quantitative boundaries.

If the three types of granite are compared quantitatively by means of their averages (Nos. II–IV, Table V, p. 554), it is seen that the biotite-granite is richest in orthoclase, the lithionite-granite in quartz, and the gilbertite-granite in plagioclase. The total micas are nearly constant. In order to compare these granites mineralogically with others, Nos. V–VII in the same table

[1] J. A. Howe, 'Handbook to the Collection of Kaolin, &c.' Mem. Geol. Surv. 1914, p. 192.

give the compositions of the granites of Rubislaw, Mountsorrel, and Shap. The values for the last-named are quoted from Dr. A. Holmes, and slides of the others were measured for the purpose.

Field relations.—Consider first the relation of the biotite-muscovite-granite of the Luxullyan area to the lithionite-granite of the adjacent Hensbarrow area. In the Pentruff series of quarries lithionite-granite is found in Mr. Vivian's quarries, and the Luxullyan type at Carn Grey Quarry; but, unfortunately, no contact of the two types could be found, and these quarries do not provide continuous sections. Nevertheless, no matter how the rocks of the two districts are compared, they are strikingly different. Topographically, the Luxullyan granite forms tors, while the lithionite-granite is characterized by rounded slopes and flat plateaux (such as Longstone Downs), covered by a mantle of decomposed rock. Mineralogically, the Luxullyan rock contains biotite and muscovite (with the characters usual in granite and abundant haloes), also a strongly-zoned acid oligoclase; while, structurally, it is always coarse in grain. In the lithionite-granite the plagioclase is smaller, un-zoned, and nearer albite in composition. Quantitatively, the proportions of the minerals are different, and there is a relatively sudden change, wherever the boundary is crossed, as is indicated clearly in the space-variation diagram of fig. 10 (p. 570). In fact, these two rocks have clearly crystallized under very different conditions, and are best regarded as separate intrusions.

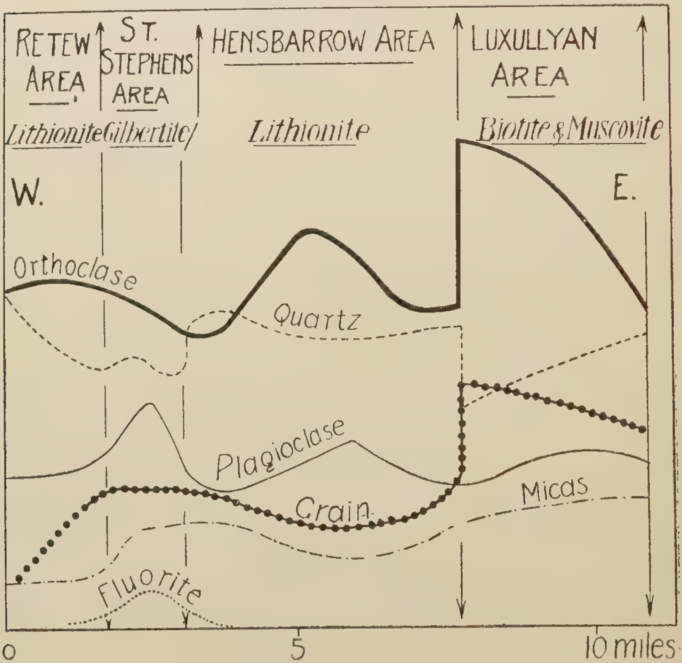
The micas of the Carn Grey rock are interesting. Muscovite and biotite, the latter indistinguishable from that of the Luxullyan rock, are present; but, in some slides, the paler biotite, grading in one and the same crystal into lithionite, is present. In fact, all three types of mica, so far as optical properties can distinguish them, are found in the Carn Grey rock. With respect to the type of mica present, then, this rock is transitional to the lithionite type; but its other characters, both mineral and structural, place it unmistakably in the Luxullyan area.

The lithionite- and gilbertite-granites evidently grade one into the other. As we approach the St. Stephen's area no radical differences are discernible, and, moreover, the lithionite type reappears gradually on the other side of that area. Structurally and mineralogically, the two types are similar. The plagioclase is rather closer to albite in the St. Stephen's area, and the grain is somewhat coarser. The quantitative boundaries overlap to a considerable extent. Undoubtedly, the two rock-types are to be regarded as transitional and nearly, if not quite, simultaneously intruded.

Quantitative variations.—Leaving the mutual relations of the types for further consideration later, let us examine the quantitative variations of the different areas with respect to the boundaries assigned to them. In order to define the quantitative

boundaries of the minerals, we may apply to each area the average for its own granite-type, and so mark out those zones in which the mineral is present in an amount greater than its average. These may be called g r o u p i n g s o f t h e s e c o n d o r d e r, so as to distinguish them from first-order grouping: that is, with reference to the mean for the whole outcrop. These new zones are shown on the original maps for the chief minerals by dotted lines, and the positive areas (that is, those with quantities greater than the mean) are shaded. The values fall into definite zones,

Fig. 10.—*Mineral-variation diagram on a 'space base' across the St. Austell granite-mass.*



which, in many cases, do not differ materially from the groupings of the first order. The new mode of arrangement may be briefly summarized.

In the case of quartz (fig. 2, p. 548) each area is occupied by a negative group more or less centrally placed. For the St. Stephen's and Hensbarrow areas these groups are well established; but, although the same tendency is exhibited in the other areas, it rests on fewer points. A tendency to the formation of a second negative area is also shown in the extreme north-east of the Hensbarrow area. Orthoclase (fig. 4, p. 556) shows

the development of central positive areas that almost coincide with the negative quartz-zones. The St. Stephen's and Hensbarrow areas have zones, elongated in the direction of their axes, of high plagioclase (fig. 5, p. 556), but the distribution of the plagioclase in the other areas is somewhat indefinite. It may also be noted that a marked positive region of fluorite practically coincides with the positive plagioclase zone of the St. Stephen's area. Lastly, the micas (fig. 6, p. 558) call for special mention. The second-order grouping does not materially differ from the first, but is remarkable for cutting across the other zones, and showing a relation with the margins of the whole mass rather than with its subdivisions.

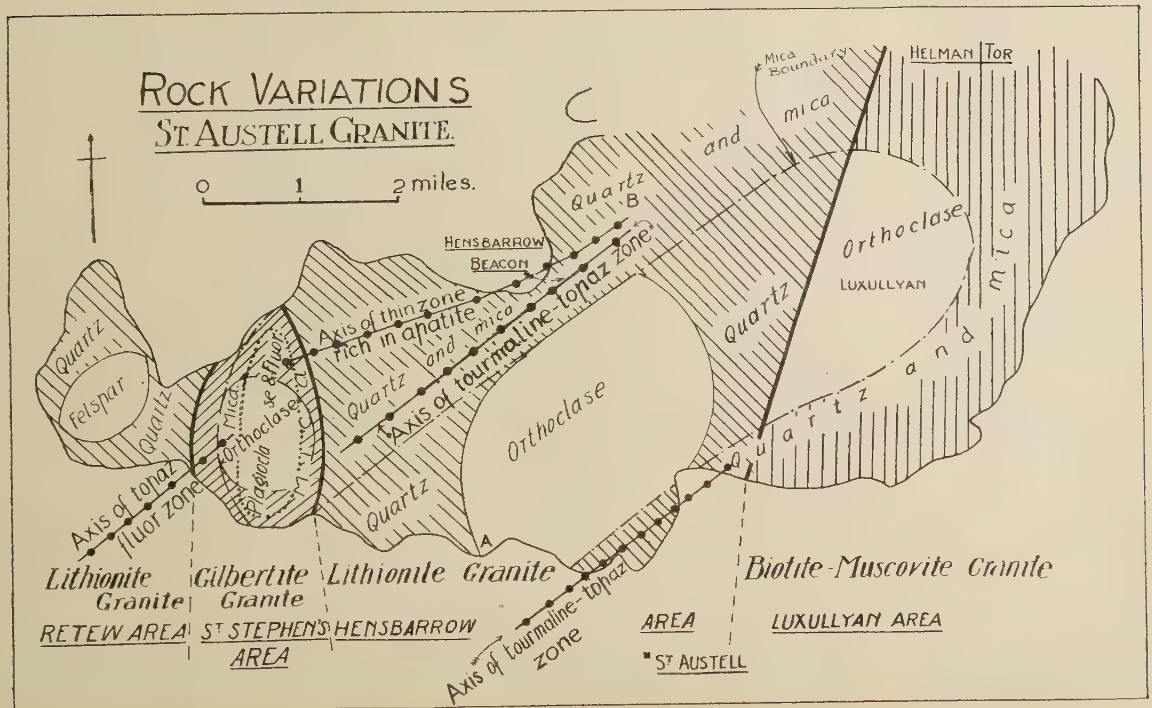
In order to present as clearly as possible the variation of the St. Austell granite-mass, fig. 11 (p. 572) has been prepared by a careful review of the lines and points of previous maps. The district is divided into areas characterized by quantitative and qualitative differences. There are, first, the three main areas with different granite-types, about which much has been said already. The quantitative subdivision relates entirely to the averages for these types. Where the name of a mineral is written within a boundary, that area contains the mineral in excess of the mean for its type; and, in addition, positive areas of quartz are shaded by lines sloping differently for regions occupied by the different granite-types. Zones with a high content of pneumatolytic minerals are indicated by their axes, and a similar device is adopted to show the narrow zone rich in apatite. Lastly, the two small occurrences of biotite-granite are marked by the letters A (St. Mewan Beacon) and B (Carnsmerry).

The small Retew area of lithionite-granite shows a tendency to have a central felspathic zone, surrounded by a quartzose zone; but the points are rather few.

The larger Hensbarrow area of lithionite-granite shows a central felspathic region, consisting mainly of plagioclase in its northern, and of orthoclase in its southern part. The orthoclase-rich portion extends down to the southern margin of the granite, where thin bands of elongated phenocrysts occur. Surrounding this felspathic zone is a marginal one rich in quartz. In addition, there are two marginal bands rich in mica: the larger along the north-western margin, and the smaller along the extreme south-eastern margin of the area. Each of these includes the axis of a high pneumatolytic zone, generally parallel to its own direction; and, finally, the northern zone includes a long narrow strip rich in apatite, elongated in the same general direction.

The St. Stephen's area of gilbertite-granite, largely quarried for china-stone, has a well-defined concentric arrangement. The centre is occupied by a positive orthoclase-zone, surrounded by a quartzose one, while there is a very narrow but central area extremely rich in plagioclase (albite) and fluorite. Practically

Fig. 11.—*Map embodying a summary of gravitative mineral distribution.*



the whole area, except a narrow strip along the western margin, is covered by a positive mica-area.

The Luxullyan area of biotite-muscovite-granite has a well-marked central orthoclase-zone, as is shown by the distribution of perthite-phenocrysts alone. This is surrounded by a marginal area characterized by quartz and plagioclase; but the actual marginal specimens show an exceptional richness in biotite. Still more detailed work is desirable in this area, and along its junction with the rock on the west.

The rock at St. Mewan Beacon, besides containing biotite and microcline, is rich in plagioclase, which shows a distinct tendency to zoning. The plagioclase of the muscovite-biotite-granite at Carnsmerry also presents many of the features of that of the Luxullyan area. At Stenalees, in the Hensbarrow area, a very felspathic occurrence of the lithionite-granite is quarried as for china-stone—the only example outside the St. Stephen's area.

Fig. 10 (p. 570) is a space-variation-diagram, or quantitative 'section' of the map from west to east, and shows the changes over the district in another way. It is drawn by having regard to the areas of the map and the values at adjacent points. The chief features to notice are the gradual changes in passing from the gilbertite to the lithionite areas, and the marked tendency to discontinuous change in passing over from the lithionite- to the biotite-granite.

The general quantitative arrangement in the areas, then, follows much the same plan. There is a more or less central area rich in orthoclase, always in large plates and often as conspicuous phenocrysts. In two of the areas there is a central core of plagioclase, and in all an outer quartzose zone. Despite peculiarities, the micas tend to concentrate at the margins, and in the western portion coincide with zones which have a high content of pneumatolytic minerals. The zonal axes are also parallel to the direction of the china-clay pits and chief lodes: that is, parallel also to directions of later pneumatolytic activity.

VII. History of the Intrusion-Phenomena.

Now, one feature demanding preliminary attention is the peculiar microstructure of the marginal phase in the lithionite areas. It has a porphyritic character, in which the phenocrysts include all the minerals; while the ground-mass is always fine-grained, and usually microgranitic or aplitic in texture. Moreover, the minerals of the ground-mass are chiefly orthoclase and quartz. A careful study of these types leads to the conviction that the porphyritic elements had already crystallized before intrusion, and had drifted into position; while the ground-mass represents the rapidly chilled mother-liquor in which they floated. Thus two periods of crystallization are indicated: one pre-intrusive, and the other post-intrusive.

The granite of the Luxullyan area is more nearly a normal

granite in its mineral content than that of other areas. The outer zone, noteworthy for biotite and plagioclase, could be explained either by Dr. A. Harker's localization of crystallization, or by Dr. N. L. Bowen's conception of the consolidation of the first intruded phase. It differs, however, as do the other districts, by having a central orthoclase-zone with a more quartzose margin: that is, by the outer concentration of a mineral of the latest stage of separation. This feature, as will be seen, also finds explanation on the grounds of a pre-intrusive crystallization.

This question of the high negative correlation of quartz and orthoclase, and the marginal position of the more quartzose zones, affects all the areas dealt with in this paper. Sinking of the individuals of earlier separation does not account for the phenomena: for, in that case, plagioclase should be centrally concentrated, especially as plagioclase has a higher specific gravity than orthoclase. On the contrary, there is a very small negative correlation between quartz and plagioclase, and their positive areas overlap, even if they do not quite coincide. Moreover, marked central concentration of plagioclase is seen only in the St. Stephen's area. Some other explanation must be sought. Examination of geological sections across batholiths shows the tendency to develop cupolas in the central parts of the roof. This leads to the conclusion that the foundering of the roof, whatever may be the cause, takes place from the centre of the sides. In these circumstances, the magmatic stream will flow most rapidly as a central column, spreading sideways to fill the chamber as the outer parts of the roof fall in; and, where the stream is deflected at the roof, a sudden decrease in velocity results. If such a stream were charged with crystalline elements, including mica-flakes, small plagioclase-crystals, and larger perthite-plates, it is evident that the check in velocity would cause a partial dropping of the load at this point. Despite their higher specific gravity, the thin mica-flakes would be carried on; the large perthite-plates would be left; some of the denser plagioclase-crystals would perhaps be carried forward, and some remain in the central parts. Such crystal-sorting by streaming explains the central disposition of the perthites, but it implies that at the time of intrusion into the present position crystallization had proceeded to some length. The mother-liquor would then be siliceous, and the remaining products of crystallization would be partly orthoclase, but largely quartz. If the central region were more completely occupied by large perthite-plates than the margins, it follows that the marginal zone after completed consolidation will contain more quartz, so explaining the negative correlation between the two minerals that predominates in this district.

The concentration of mineralizers in the western areas has had other effects besides the formation of peculiar minerals. The occurrence of narrow positive zones of pneumatolytic minerals

within the positive mica-areas does not necessarily indicate a causal connexion; but the concentration of mineralizers has, nevertheless, had its effect upon the type of mica. I have already pointed out that the lithionite of the Hensbarrow area is sometimes so bleached as to be nearly or quite colourless in thin sections; and such bleached lithionites occur along the areas rich in pneumatolytic minerals, at Hensbarrow Beacon; at Trenance; and near Dubber's Works. Finally, the St. Stephen's area is occupied by an especially rich zone of fluorine-minerals, and here the mica is entirely of the colourless gilbertite type, doubtless closely allied to, and developed from, the lithionite. The effect of the mineralizers is apparently to retain the silicates of iron in solution, and ultimately perhaps to remove them from the granite and deposit them later in mineral veins.

There remain two other phenomena, especially characteristic of the St. Stephen's area: namely, the late separation of an apatite filled with inclusions, and the occurrence of nearly pure albite as the plagioclase. It has been shown that all the lime present in bulk analysis is sufficient to account for the phosphoric acid and part of the fluorine only, and it is suggested that the mineralizers have operated on the lime in much the same way as upon the iron. They have retained it in solution so that none was available for the formation of anorthite; the temperature of separation of apatite was lowered, and the remainder was deposited as fluorite in replacement in the very last stages of consolidation, or still later. The general evenness of grain in the St. Stephen's area, and its somewhat greater size, when compared with the lithionite areas, may also be due to the further concentration of mineralizers in the district.

In short, the history of the intrusion of this granite-mass, so far as the data permit it to be deciphered, begins in the east with the intrusion of a magma partly crystallized, and already containing large perthite-crystals, but still possessing a relatively high temperature and involving a relatively long time-interval before the completion of crystallization. The mica-zoning of the perthites probably indicates the period of injection. The perthite-plates carried up in a central stream were largely suspended at the point where the velocity was checked by deflection. Crystallization again slowly proceeded, both by addition to old crystals and by the initiation of new centres, and a coarse-grained igneous rock resulted. Towards the later stages the country on the east was gradually and progressively invaded, and the few occurrences of biotite-granite may have formed the commencement of the invasion. The new intrusive material had advanced farther along the course of crystallization, and to such an extent that some of the quartz had already begun to separate. At contacts with relatively cold country-rock rapid crystallization of the already cooled residual liquor took place, embedding the earlier crystals in an aplitic ground-mass; while, in the more central parts, the further crystallization proceeded rather

by additions to crystals already present. In this region also, crystal-sorting according to the velocity of the incoming stream again took place, so that the larger plates of the perthite had a central deposition. Final stages of intrusion, or rather of crystallization, took place in the St. Stephen's area, accompanied by a great concentration of mineralizers, which helped towards the production of a uniform grain, removed the iron compounds, and retained the lime in solution to a late stage.

Discussion.

Dr. J. S. Flett said that, in his studies of the Cornish granites, he had been impressed rather with their uniformity than with their differentiation. It was the remarkable pneumatolytic facies that constituted their chief attraction from a petrological standpoint. It was interesting, consequently, to see that by the detailed methods of modern investigation distinct types could be identified and their distribution mapped. The process employed was certainly laborious, but promised to yield useful results.

Dr. A. Brammall expressed appreciation of the Author's methods of investigation, and enquired whether, before rejecting pneumatolysed types for the purposes of this work, he had tested the possibility of an approximate mass-equivalence between primary minerals such as biotite, ilmenite, sphene, etc., on the one hand, and secondary minerals such as tourmaline, brookite, anatase, on the other; this equivalence was observed in the case of the Dartmoor Granite. He also asked whether zoned tourmalines of the type shown were regarded by the Author as definitely primary: similar occurrences on Dartmoor were certainly secondary.

The Author, in reply to Dr. Brammall, stated that the investigation indicated merely a very slight correlation between tourmaline and biotite; but the general relation could only be investigated by considering granites as a whole. Much of the zoned tourmaline in the normal granite appears to be of the same date as the unzoned, and is regarded as primary.

21. *The* Miocene *of* Ceylon. By Edward James Wayland, M.I.M.M., F.G.S., and Arthur Morley Davies, D.Sc., F.G.S. (Read May 10th, 1922.)

[Plates XXVIII & XXIX—Fossils.]

Part I.—Stratigraphy. (By E. J. W.)

It has long been known that fossiliferous limestones occur in the Jaffna peninsula in the extreme north of Ceylon, but until recently they have received little attention, and nothing approaching a detailed account of them appears to have been published.

At various times between 1914 and 1916 (inclusive) in the capacity of Assistant Mineral Surveyor for Ceylon, I carried out geological investigations over a stretch of more than 800 miles of the coast-line of the island. During the progress of this work sedimentary beds were frequently met with; and the best-developed group of these—the Miocene—is dealt with in this paper. It will be shown that the Jaffna limestones are of Miocene age, that similar limestones occur elsewhere in Ceylon, and that Miocene rocks of other facies also occur.

I am at a disadvantage in that all my field-notes, being the property of the Mineral Survey, remain in Ceylon; but sufficient information is contained in private note-books to allow of a general description.

Prior to Dr. Davies's determination of the contained fossils the age of the Jaffna limestones was very uncertain; for, while I recognized them as Tertiary, and regarded them as probably Eocene, a previous author believed them to be of Cretaceous age.[1] Sir Emerson Tennant regarded them as a recent coral-formation,[2] and this view is still held by engineers and others who have occasion to deal with them; while Mr. J. S. Boake, in a very ingenious, if entirely imaginary, representation of Ceylon geology,[3] depicted them as covering lateritic deposits which can be demonstrated not to antedate the human period.[4]

The two facies of the Miocene are (*a*) calcareous, typically shown in the Jaffna peninsula, and (*b*) areno-argillaceous, typically shown at Minihagalkanda, Southern Province. The limestones attain considerable thickness, and are highly fossiliferous. The areno-argillaceous beds are usually less than 50 feet thick, and unfossiliferous: only at Minihagalkanda do they include thin intercalations of limestone with an abundant fauna.

[1] A. C. Dixon, 'The Rocks & Minerals of Ceylon' Journ. Ceylon Branch, Roy. Asiat. Soc. vol. vi, pt. 2 (1880) p. 39 [22].

[2] 'Ceylon' 1860, pp. 12–20.

[3] 'Mannar: a Monograph' Colombo, 1888.

[4] E. J. Wayland, 'Outlines of the Stone-Ages of Ceylon' Spolia Zeylanica, vol. xi, pt. 41, Oct. 1919.

Geology of Type-Localities.

(1) Jaffna.—The Jaffna peninsula is a rock-platform (plain of marine denudation) covered with a bright red soil (locally absent, however, as near Puttur) and fringed, especially along the eastern coast, by sand-dunes. The highest part of the peninsula is at Kirimalai, where a limestone and calcareous sandstone-hill rises gently to an altitude of about 50 feet above the sea.

Fig. 1.—*Sketch-map of Ceylon and the adjacent part of India, on the scale approximately of 1 : 7,500,000.*

[The dotted area is the low-lying limestone area of the Northern and North-Western Provinces, within which are the outcrops of Miocene beds yielding *Orbiculina malabarica*. The black areas are over 1000 feet above sea-level, and correspond, in Ceylon, to Tennant's 'hill-country', the area left blank being his 'maritime belt', and the dotted areas his 'Madrepore.'

S.U.V.=Sinna Uppu Villu. Of the two unnamed rivers, the northern-most, and shorter, is the Pomparippu river; the other is the Kalu Oya.]

Practically the whole solid geology of the Jaffna peninsula, the islands on the west, and much of the mainland on the south and south-west, consists of a very light-coloured (usually creamy but sometimes greyish) limestone. It varies in texture from a somewhat cellular material, occasionally full of corals, to a massive rock

in which gasteropoda are common, and appears to represent accumulations associated with ancient coral-growth. The rock usually weathers into a honeycombed mass.

The following petrographic notes were made in the Geological Department of the University of Birmingham. I have to thank Prof. W. S. Boulton for placing a microscope and other facilities at my disposal.

Sections of limestones from Kirimalai and Pallai (Jaffna peninsula) and north of the Pomparippu (North-Western Province) agree very closely. They are sand-free foraminiferal limestones with remains of calcareous algæ (*Lithothamnium*), echinoid-radioles, and molluscan tests, set in a cement of crystalline calcite. Another from Puttalam (North-Western Province) shows fewer complete tests of foraminifera, and the matrix is a consolidated limestone-mud. Another from the bed of the Kal Aru is distinguished by containing small derived pebbles of material similar to the rock itself; much iron-staining is present, and in several instances ferruginous material fills the interior of foraminiferal and other tests.

In addition to these pure limestones, grits with calcareous cement occur at several localities, at one of which they contain a fauna similar to that of the limestones. At Kirimalai the grit (here fossiliferous) has grains mostly of quartz, extremely angular and small (0·1 to 0·2 mm.), with a few comparatively large grains, some exceeding 2 mm. in diameter. Grains of a black iron-ore, possibly ilmenite, but more probably magnetite, are present; garnet occurs sometimes, while zircon, tourmaline, corundum, monazite, and biotite are still less common. One slide contains a few small pebble-like inclusions of angular quartz-grains set in an iron-stained calcareous matrix. Iron-staining occurs elsewhere in small patches in the slides. Between Karuvalakuda and Palugahatuve a similar grit occurs; but the quartz-grains are larger (0·25 to 0·6 mm.) and less angular, garnet and black iron-ore are more abundant, and there are tiny pieces of fibrous minerals, apparently sillimanite and wollastonite. Apart from molluscan tests filled with large calcite-crystals, there are few organic fragments. Near Point Pedro the limestone contains a good deal of quartz-sand; while north of Palavi there is a calcareous conglomerate containing quartz-pebbles which measure an inch or more in length.

Occasionally along the beach, particularly near Point Pedro, grey and brown chert-pebbles closely resembling flint are to be gathered: they probably represent the remains of silicified layers of limestone. Examples of this replacement are not known *in situ*; but some pieces of opaline material containing characteristic limestone fossils, picked up on the mainland in the dry bed of the Kal Aru, suggest very strongly that such local replacement has occurred. Under the microscope, this material from the Kal Aru is seen to consist of opal and chalcedony showing botryoidal structure in cavities: there are many unidentifiable traces of organisms.

The Jaffna Miocene is but very slightly disturbed. Slight buckling is indicated by a few gentle folds running in an east-north-easterly direction. Vertical movement, actual or relative, has been more marked.

(2) Minihagalkanda.—Minihagalkanda ('man-rock-hill') is so called from a stack separated from the main rock-mass and carved by denudation into a striking resemblance to a standing figure. It lies about 5 miles east of the Yala river, and is composed of altered gneiss, though it is for sedimentary strata that the vicinity is most noteworthy. These crop out for a distance of about 2 miles, starting 2 miles east of the Pilinawa outlet, and occur in cliffs about 100 feet high. They stand well back from the sea, being separated from it by sand-dunes. Landwards the high ground extends for about a quarter of a mile, and then descends steeply to the jungle-covered plains of recent alluvium only a few feet above sea-level. (This peculiar ridge-like elevation of soft rocks more or less parallel with the shore is seen again near the mouths of the Kalu Oya and Pomparippu rivers, in the North-Western Province.) The deposits must have once had a greater lateral extension, the more landward parts having been removed by denudation, while the remainder was preserved by the protective agency of blown sand at a time when the land stood lower in relation to the sea. Evidence enough exists of such a former relation, for the sedimentary deposits rest upon a sea-worn floor of ancient crystalline rocks in which can be traced ancient gullies and small inlets, now high and dry and some considerable distance from the water's edge; some of them contain reconstructed deposits derived from the sedimentary rocks that stand well back from them. An ancient line of cliff can also be traced.

The present description deals chiefly with the exposures to be seen in the walls of a natural amphitheatre spanning 1200 yards at Minihagalkanda, where the succession is best displayed. Near the shore the basement-bed is an unfossiliferous ferruginous grit, varying from 4 to 6 feet in thickness; it tends to thin landwards, and near the north-eastern part of the amphitheatre is separated from the gneiss by a thin bed of pipe-clay. On the east-north-east a scoriaceous-looking sandstone replaces the grit; it is about 10 feet thick, and is separated from the gneiss by a bed of lithomarge 6 to 10 feet thick. Eastwards of this the gneiss rises up, and is covered immediately by red earth.

Above the grit come about 25 feet of poorly-consolidated gritty argillaceous beds; their upper limit is a calcareous band which, traced eastwards, becomes more marked while others appear beneath it. At about 1000 yards from the south-western limit of the exposures no less than five calcareous bands separated by gritty argillaceous beds are to be seen: here they are sufficiently pure to be called limestones, but possess a decidedly nodular character. They are either compact and hard or cavernous, and in that case, sometimes but not always, softer. Under the microscope

they are seen to be foraminiferal limestones containing many well-preserved organisms in a matrix of calcareous mud. From these limestones the Miocene fauna was obtained. Above the upper limestone-band is a stratum of clay, 6 or 7 feet thick, containing pebbles which increase in number and size upwards. Above this again lies a red deposit packed with ferruginous pisolitic concretions, which vary in diameter up to a maximum of about half an inch, large concretions predominating. Finally, the red lateritic earth, so conspicuous throughout the low country of Ceylon, occurs to a thickness of 15 to 18 feet. Like the lœss of China and the limon of Belgium, this stands vertically in the cliff-face.

The pisolite may represent an ancient bog-iron-ore deposit, while the fluviomarine origin of the pebbly clay is not improbable; neither they nor the red earth above, which here seems to be an ancient and lateritized blown sand, belong to the Miocene. All three contain artefacts, and the lower two, at any rate, are probably Pleistocene.[1]

The section may be tabulated as follows:—

	Maximum thickness in feet.	*Type of junction.*	*Age.*
7. Soil	?		Holocene.
6. Red earth	18		
		Conformable.	
5. Pisolitic ironstone	17		Pleistocene.
4. Pebbly clay	7		
		Conformable.	
3. Areno-argillaceous beds, with nodular limestone	25		Miocene.
2. Ferruginous grit and sandstones, etc.	10		
		Unconformable.	
1. Gneisses, etc. (generally kaolinized and locally separated from the sedimentary deposits by a bed of lithomarge).	?		Pre-Miocene (probably pre-Palæozoic).

These Miocene beds appear to have been deposited in a small basin. They have received a slight eastward tilt since deposition.

Some 2 miles farther east, near Udapotana, areno-argillaceous beds occur beneath red earth in a tall cliff. If lithology is to be relied on, these also are Miocene.

[1] E. J. Wayland, *op. jam cit.* p. 99.

Near Weligama (in the extreme south of the island, more than 80 miles from Minihagalkanda) a mile or so inland, a sandstone, dipping landwards, is exposed in some drainage-trenches. This may possibly be Miocene, but I only saw these exposures when on active service during the riots of 1915, and could make no detailed examination of them.

Relation of the Jaffna and Minihagalkanda beds.—The thickness of the Jaffna limestone is unknown, and its base has never been seen in the peninsula. It is probably to be reckoned in hundreds of feet. Assuming that no allowance need be made for overlap, the Minihagalkanda beds, resting as they do upon the crystalline rocks, must represent the base of the Ceylon Miocene, and should therefore be somewhat older than the Jaffna deposits. The palæontological evidence seems to confirm this view.

(3) Other Miocene areas.—Except for the possible Miocene sandstone at Weligama, no sediments likely to be Miocene are known along the southern and western coasts between the Minihagalkanda district and Puttalam (8° lat. N.). From here to about 9° lat. N., both along the coast and inland there are many exposures of limestones yielding the Jaffna fauna and other possible Miocene strata. In the southern part of the Mannar and western part of the Anurudhapura districts, where rivers have cut into these beds, the following general succession can be made out:—

4. Red earth.
3. Areno-argillaceous series.
2. Limestones of Jaffna facies.
1. Calcareous beds.

The only doubtful point in this sequence is the position of the calcareous beds, which are nowhere seen to underlie the others, but are placed at the base as being the only strata seen to rest directly upon the crystalline complex (except the red earth, which overlaps the rest). These calcareous beds are full of tiny vermicular cavities, and contain strings of grey and white limestone-nodules. They are exposed along the Moderagam river (Upper Aru) near the Tekkam (a large masonry dam built many centuries ago, now difficult to find in the heart of the jungle), and within a few miles of it along the course of the Paymadu Oya, Kurukatum Aru, Kombankutti Oya, and south-east of Kuttian Kullam.

The fossiliferous limestones, besides occurring in the inland districts mentioned above, occur also in the Puttalam district, at 1½, 5½, and 6 miles north of the Pomparippu river, along the Mannar track; along the coast south of the Kalu Oya, north of the Pomparippu, and west of Sinna Uppu Villu, where they form turtle-back hills the first of which presents a sheer 50-foot cliff to the sea; also in the northern part of the low-lying Kalpitaya peninsula and the islands near it. Localities which have yielded fossils are indicated in the palæontological lists (pp. 586–87).

The areno-argillaceous series appears to rest unconformably upon the limestones. . It seems to be identical with a series appearing along the coast east and north of Kudremalai Point and extending almost to Arippu, which shows striking resemblances with the areno-argillaceous rocks of Minihagalkanda.

South of Kudremalai Point another series of sandy beds appears in a cliff 40 feet high. Its relationship to the areno-argillaceous series is not clear: the latter may either be faulted or deposited against it. In either case the sandy series is probably the older. The succession shown is the following, the two lowest divisions forming the main part of the 40-foot cliff:—

5. Red earth.
4. Fine-grained and very deep-red sandstone, denuded to a mass of small pinnacles.
3. Impure, somewhat nodular limestone, weathering into small dome-like masses.
2. False-bedded sandstone, with fossils (land-shells).
1. Sandstone, dipping generally 30° east by south.

A bed similar to No. 4 is seen in one of the inland sections, between the red earth and the areno-argillaceous series.

The fossils from the false-bedded sandstone were submitted to Mr. G. K. Gude, who kindly reported on them as follows:—

'I would without hesitation say that they belong to the family Zonitidæ, and am strongly inclined to refer them to the genus *Ariophanta* (=*Xestina*) many species of which are Ceylon natives. It is unfortunate that the specimens are in rather poor condition, and specific determination, I am afraid, is out of the question.'

The only conclusion to be drawn from these fossils is that the sandstone is Kainozoic. It is not likely to be Miocene, or at least not Upper Miocene, since marine deposits of that date occur so near; but whether pre- or post-Miocene must remain uncertain.

Sandy beds without fossils also appear along the coast, between Ambalama and Karaitivu.

White argillaceous beds, possibly Miocene, but unfossiliferous, occur on the coast at Ambalama, and inland, beneath red earth, at Iranamadu.

Conclusion.

To sum up, we know that at Minihagalkanda the local base of the deposits which Dr. Davies has shown to be of Miocene age is represented by inconstant areno-argillaceous beds with limestone partings; the Miocene of Jaffna, of which neither the base nor the top is known, is essentially limestone; in part of the Anurudhapura district, limestone closely similar to that of Jaffna is succeeded by beds remarkably like those of Kudremalai and the lowest Miocene of Minihagalkanda. So it is possible that the Ceylon Miocene represents a complete cycle of movement and deposition: that is to say, depression followed by uplift, the two shallow-water phases being represented by areno-argillaceous beds of no great thickness,

and the deeper-water phase—probably one of comparatively long duration—by thick deposits of limestone.

As the evidence for this view is not complete, a possible alternative explanation of the facts may be indicated. If the lithological resemblances between the areno-argillaceous beds of the North-Western Province and those of Minihagalkanda imply identity of age, then the latter would be younger than the Jaffna limestones instead of older, and their direct contact with the crystalline rocks would be due to southward overlap. This appears to us a distinctly less probable explanation of the facts than the one that we have adopted.

Although oscillations have taken place more recently, nothing comparable to the Miocene depression is known to have left its record in the Pliocene and Pleistocene geology of Ceylon.

Part II.—The Faunas of the Miocene of Ceylon.
(By A. M. D.)

The marine fossils collected by Mr. Wayland from the Northern, North-Western, and Southern Provinces of Ceylon consist of foraminifera, corals, echinoids, and molluscs. Of these four groups the representatives of the first and third are often beautifully preserved, though sometimes almost impossible to extract from their matrix; the corals are badly preserved; while the condition of the molluscs is mediocre, and they are generally represented by internal casts, or by specimens in which essential features (such as the hinge of lamellibranchs) cannot be seen. The majority of the fossils show so close a resemblance to species figured either by J. de C. Sowerby from Kach, or by A. d'Archiac & J. Haime from Sind, that there can be no question that they represent a normal marine Indo-Pacific Neogene fauna. Many of them also show close relations to recent Indo-Pacific species, and some resemblances to Californian Miocene fossils were noted; but very few suggest a comparison with European forms, Tertiary or recent.

The two localities which yielded the greatest number of fossils are Kirimalai in the extreme north of the Jaffna peninsula, and Minihagalkanda almost in the extreme south of the island. From other localities only a very few fossils were brought. They are, in geographical order from north to south:—(1) east of Kankesanturai (near Kirimalai); (2) near Pallai, in the south-eastern part of the Jaffna peninsula; (3) from the bed of the Kal Aru, which flows to the western coast about 8° 40′ lat. N.; (4) north of the Pomparippu, on the same coast, about 8° 20′ lat. N.; (5) Puttalam (Anuradhapura road) on the same coast, about 8° lat. N. In all these cases the rock is a foraminiferal limestone. From the bed of the Kal Aru came also a chert, showing very obscure organic structures. The land-shells from Kudremalai have been dealt with in Part I (p. 583).

In studying the marine fossils I have had the advantage of comparing them directly with Sowerby's and A. d'Archiac & Haime's types, now preserved at the British Museum (Natural History). I owe many thanks to Dr. A. Smith Woodward for facilities given for this work, to Mr. R. B. Newton for criticism and advice during its progress, and to Mr. G. C. Robson for help in examining recent Indo-Pacific shells. I visited Paris with the object of studying other Miocene collections, and it is with great pleasure that I recall the very courteous and helpful way in which I was received by French palæontologists, in particular MM. G. F. Dollfus, H. Douvillé, M. Cossmann, and M. Cottreau, who devoted much time to searching through collections and to the discussion of points of interest. To Mr. G. S. Sweeting I am much indebted for assistance in the photography of specimens.

A complete series of the fossils, including all type- and figured specimens, has been presented by Mr. Wayland to the British Museum (Natural History).

The collections of fossils described and figured by J. de C. Sowerby from Kach, and by A. d'Archiac & J. Haime from Sind, were in both cases stratigraphically mixed. Subsequent sorting has not been facilitated by the fact that in each case, by a strange fatality, most of the specimens are recorded as from a 'ghost' locality—'Soomrow' in Kach (identified by Wynne as possibly Trummo) and the 'chaîne d'Hala' in Sind, which appears to exist solely in school geography-books. The only published attempt at a reference of the fossils to their several horizons is that by Fedden (1879 [1]), although much unpublished information is probably in the possession of the palæontologists of the Indian Geological Survey. In the following tables (pp. 586–87) the columns that indicate previous records of the species with which the Ceylon fossils seem most closely comparable are based principally upon Fedden's tables.

When we compare the lists from the two most prolific localities, Kirimalai and Minihagalkanda, we see that they have few species in common. Yet, if we take all those identifiable with Sowerby's or A. d'Archiac's types, and classify them according to the probable stratigraphical position as given by Fedden, we get very little guidance as to age, either absolute or relative. In both cases we find species of Gaj and pre-Gaj age with others that are most comparable with recent forms. Any deduction as to age, based on their relative proportions, is unsafe for several reasons:—(1) few of the identifications are exact, and, in the case of a fauna which evolved so slowly as that of the Indian Ocean (Vredenburg, 1911), approximate identifications do not form a safe basis for the percentage method; (2) it was generally easier to compare these fossils with other fossils than with recent forms, hence the references to recent species are probably fewer than they might have been if the Ceylon fossils had been better preserved; (3) Fedden's allocation of species to horizons was tentative only.

[1] Dates in parentheses refer to the list of papers at the end (pp. 600–601).

I.—Northern and North-Western Provinces.

[A. & H. = A. d'Archiac & J. Haime. r (rare) denotes only one specimen found; c (common) denotes from two to six; a (abundant) denotes from eight to fifty.]

	Jaffna Peninsula.			N.W. Province.			Previous records of the same or comparable species.		
	Kirimalai.	E. of Kankesanturai.	Near Pallai.	Bed of Kal Aru.	N. of Pomparippu.	Puttalam.	Pre-Gaj.	Gaj.	Post-Gaj and Recent.
Algæ.									
Lithothamnium sp.	c	...	...	...	c				
Foraminifera.									
Orbiculina malabarica (Carter)	a	...	a	...	a	a	Travancore.		
Sorites sp. [*Orbitolites* of simple type]	...	...	r						
Alveolinella (Flosculinella) sp.	c	...	c	...	?	...	Miocene of Java.		
Spiroclypeus (?) sp., cf. *pleurocentralis* (Carter)	r	...	...	...	...	...	Miocene of Arabia & Borneo.		
Miliolidæ (various)	a	...	a	...	a				
Lamellibranchia.									
Arca peethensis (?) A. & H.	r	...	...	...	...	...	...	×	
Limopsis sp.	...	...	...	...	r				
Pteria [*Avicula*] sp., cf. *suessiana* Nœtling	r								
Pecten favrei A. & H.	c	...	...	...	c	...	...	×	
Spondylus rouaulti A. & H.	c	...	...	...	...	...	×		
Cardium sharpei (?) A. & H.	r								
Tellina sp., cf. *exarata* J. de C. Sowerby (but larger, stouter, and more truncated)	r								
Gastropoda.									
Trochus cognatus J. de C. Sowerby	r	...	...	...	...	...	...	×	
Trochus sp.	r	...	...	...	r				
Phasianella oweni A. & H.	r	...	...	...	...	...	×		
Natica rostalina (?) Jenkins	r	...	...	...	...	...	Java & Karikal.		
Cerithium pseudocorrugatum (?) A. d'Orbigny	c	...	...	...	...	...	×		
Cerithium sp., cf. *rude* J. de C. Sowerby	c	...	...	...	...	...	×	×	
Strombus spp.	a	...	...	r					
Ovula ellipsoides, var. b A. & H.	c	...	...	..	...	...	×		
Semicassis cf. *sculpta* (J. de C. Sowerby)	c								
Semicassis cf. *phillipsi* (A. & H.)	r	...	...	...	...	...	×		
Semicassis booleyi (G. B. Sowerby)	r	...	...	...	...	...	...	...	×
Oliva pupa J. de C. Sowerby	c	...	...	...	...	...	×	×	
Conus brevis J. de C. Sowerby	?	r	...	...	...	...	...	?	
Conus sub-brevis A. & H.	r	...	...	...	...	...	...	×	
Conus, 2 spp.	c								

II.—Southern Province.

[Only locality: Minihagalkanda.]	Minihagalkanda.	Previous records of the same or comparable species. Pre-Gaj.	Gaj.	Post-Gaj and Recent.
Foraminifera.				
Orbiculina sp. (Martin, Samml. Geol. Reichs-Mus. Leiden, n.s. vol. ii, pt. 7, 1917, p. 277 & pl. v, fig. 142)	r			
Operculina sp.	c			
Spiroclypeus orbitoideus H. Douvillé	r	Miocene of Borneo.		
Actinozoa.				
Montlivaltia brevis Duncan	r	...	?	
Hydnophora plana (?) Duncan	r	...	?	
Porites sp.	r			
Other corals, unidentifiable	a			
Echinoidea.				
Clypeaster depressus J. de C. Sowerby	c	...	×	
Clypeaster sp., aff. *carteri* Duncan & Sladen and *oblongus* J. de C. Sowerby	c	?	×	
Schizaster sp.	c			
Lamellibranchia.				
Pinna sp., cf. *bullata* Swainson	c	...	...	×
Pinna pachyostraca sp. nov.	r	Miocene of Greece?		
Amusium subcorneum (A. & H.)	c	...	×	
Spondylus waylandi sp. nov.	c			
Ostrea virleti Deshayes	c	...	...	×
Ctenocardia sp., aff. *fornicata* (G. B. Sowerby)	r	...	...	×
Lævicardium sp., aff. *biradiatum* (Bruguière)	r	...	...	×
Lævicardium sp., aff. *lyratum* (G. B. Sowerby)	r	...	...	×
Cardium sp., cf. *subalternatum* Jenkins	c	Miocene of Java.		
Trachycardium (?) picteti (A. & H.)	r	×		
Opisocardium sp., aff. *subretusum* (G. B. Sowerby) [*cf.* also *O. limaforme* (H. Woodward) Geol. Mag. 1879, p. 388 & pl. x, fig. 16]	r	...	...	×
		Miocene of Nias.		
Corbis subelliptica (?) A. & H.	r	×		
Chama sp.	r			
Trapezium [*Cypricardia*] *carteri (?)* (A. & H.)	c	×		
Trapezium sp.	r	Mediterranean		
Cardita crassa (?) Lamarck	r	Miocene.		
Cardita intermedia J. de C. Sowerby, *non* Lamarck = *C. sowerbyi* A. d'Orbigny *teste* Fedden	c	...	?	
Cardita sp.	r			
Chione (?) cancellata (J. de C. Sowerby)	a	×	×	
Chione (Omphaloclathrum) granosa (J. de C. Sowerby)	a	×	×	
Gastropoda.				
Trochus cognatus J. de C. Sowerby	c	...	×	
Trochus subcognatus A. & H.	c	...	?	
Xenophora cumulans (A. & H. *non* A. Brongniart)	c	×		
Phasianella oweni A. & H.	c	×		
Natica (*Ampullina*) sp. [*cf.* Fuchs, pl. vi, fig. 11]	c			
Natica sp.	c			
Cerithium pseudocorrugatum (?) A. d'Orbigny	c	×		
Cerithium, 2 spp.	c, r			
Strombus sp., cf. *spinosus* Martin	c	Miocene of Java.		
Strombus sp., cf. *fortisi* A. & H. *non* Brongniart	r			
Ovula ellipsoides (?) A. & H.	c	×		
Cypræa prunum (?) J. de C. Sowerby	r	×	×	
Melongena (?) sp.	r			
Conus brevis J. de C. Sowerby	c	...	?	
Conus sp.	c			

In regard to the bulk of the two faunas, therefore, we have no justification for considering their differences as of age-value: they might be in part facies-differences, in part accidental differences of collection. But, when we come to consider certain definite species, the case is different. At Minihagalkanda only we find two well-marked forms not on the lists of A. d'Archiac or Sowerby—*Ostrea virleti* Deshayes, and an abnormally thick *Pinna* (*P. pachyostraca* sp. nov.); while at Kirimalai and other localities in the northern half of the island, but not at Minihagalkanda, we find *Orbiculina malabarica* Carter.

Ostrea virleti is a well-marked species with a remarkable geographical distribution. It was first found (Deshayes, 1836) north of Methone in the south-western corner of the Peloponnesus; but its exact horizon there cannot be stated. Bertrand & Kilian (1889) record it from Saleres in the South of Spain, dating it as Helvetian. At Eregli on the northern coast of the Gulf of Xeros, in Thrace, it was recognized by Mr. R. B. Newton (1904) as Vindobonian. On the south side of the Mediterranean it was found by Prof. J. W. Gregory (1911), in the post-Aquitanian Miocene limestone at the Caves of Lethe, Cyrenaica; by K. A. von Zittel (1883) in the Siwa Oasis; and by the Egyptian Geological Survey through a wide range of latitude on the western side of the Red Sea, and in Sinai (Hume, 1916). In Armenia and Persia it has been recorded at intervals from west of Erzerum to east of 55° long. E. (Oswald, 1912; Stahl, 1911). Dr. Oswald dates it in all cases as lowest Tortonian; but Stahl refers it to the Lower Mediterranean stage (Burdigalian). All these localities, so far, come within the area of the Miocene Mediterranean (though the form is unrecorded from the Vienna Basin); but it has been lately discovered, on the one hand by Gregory (1921) as far south as Maunguja, near Mombasa, and on the other by Pilgrim in the Lower Hinglaj or Talar Beds of the Mekran coast (Vredenburg, 1911). The former of these occurrences was apparently not *in situ*; but in the latter it is associated with a Gaj fauna, and Vredenburg at first assigned to it a Burdigalian age, though in his latest paper (1921) he inclined to a position as high as Pontian for the Talar Beds.

In Burma *O. virleti* was described as *O. peguensis* by Nœtling (1901), and present knowledge of its age in this region is summed up as follows by Vredenburg (1921, pp. 251, 258, 259):—

'*O. virleti* and *O. digitata* [*digitalina*] var. *rohlfsii* (Nœtling's *O. peguensis* and *O. promensis*) occur together in the basal part of the Akauktaung Series at Yethyauksan. [These beds are] probably the marine equivalents of the Irrawadi Series—probably equivalent to the Talar stage of the Mekran Series and to the Odeng Beds of Java; or else mainly intermediate in age between the zone of *O. latimarginata* and the Irrawadi Series, and, if so, equivalent to the Nahan, to the Lower Manchhar, and in Java to the Tji Lanang Series—either Pontian or Vindobonian.'

Thus *Ostrea virleti* is one of the very few Miocene species that appears to have lived in both the Mediterranean and the Indian Ocean, and the beds in which it occurs have been ascribed to

various dates from Burdigalian to possibly Pontian, with a balance of opinion in favour of Vindobonian, and perhaps of Upper Vindobonian (Tortonian). It is possible, of course, that distinct species may be confused under this name; but, although a variable form, it has features that are clearly marked, and there is no recognized species with which it can well be confused. It is not quite unique in its geographical distribution. Suess (1885) long ago pointed out that *Placuna miocenica* was a distinctly Indo-Pacific element in the Miocene of Siwa, and Deshayes described from the same series of beds as *O. virleti* in Greece a thick-shelled *Pinna* which is possibly the same as that found with it in Ceylon. Further, there seems to be an affinity between the species of *Spondylus* associated with *O. virleti* in Egypt and Ceylon respectively, and the same may be said, more doubtfully, of the species of *Strombus* and *Natica*.

It is noteworthy that in Burma and on the Mekran coast *O. virleti* occurs among the latest marine Miocene deposits, which have freshwater equivalents at no great distance, and are followed by a great series of freshwater beds. In Ceylon, on the contrary, it seems to mark the first transgression of the sea over a very ancient land-area. This affords a very clear example of Prof. Haug's principle that marine regression from the geosynclines is contemporaneous with marine transgression on the continental areas (Haug, 1900). In the Mediterranean region, owing to the greater complexity of the earth-movements, the contrast is not so obvious. In Egypt the *O.-virleti* Beds transgress on to part of a continental area depressed between two series of faults; elsewhere they usually rest, unconformably, upon earlier Miocene. As Prof. Haug has said,—

'Le Tortonien correspond . . . . à une phase de retrait [dans les régions alpines], car l'invasion de certaines parties de la région alpine par les eaux du "2ème étage méditerranéen" est due, non pas à une "transgression", ni même à une "ingression", mais bien à une "irruption" de la mer, due à des effondrements.' (1900, p. 707.)

If, then, *Ostrea virleti* dates the moment when the sea was beginning its invasion of continental areas while still lingering in parts of the geosynclines, its circumstances gave the best opportunity for a possible short-lived shallow-water connexion between the Indian Ocean and the Mediterranean, enabling this oyster and a very few other species to migrate from the former to the latter. This, at least, is the direction in which the other species spread, and, though *O. virleti* is usually thought of as a Mediterranean form, it must be remarked that the few recent species that offer any suggestion of affinity to it are all Indo-Pacific forms, and a closely allied species (*O. vespertina* Conrad) is found in the Upper Miocene of California.

The fundamental antithesis between the continental area of Ceylon and the Himalayan-Malayan geosyncline will explain why *Orbiculina malabarica*, which characterizes the Miocene of Northern Ceylon and Southern India, should be unknown else-

where. That the *Orbiculina* Limestones are later than the *O.-virleti* Beds was inferred by Mr. Wayland from the stratigraphical evidence (p. 582), and is independently suggested by the restricted geographical distribution of that very striking foraminifer. It is true that, from Kebang Sokkoh, in Java, Martin has described an *Orbiculina* associated with other foraminifera, such as occur with *O. malabarica* in Ceylon (*Flosculinella*, *Sorites*, abundant Miliolidæ); but the Java species exhibits characters suggestive of an ancestor of *O. malabarica* (longer persistence of the spiral stage), and it is associated with *Miogypsina* in abundance, whereas no trace of that genus has yet been found in Ceylon.[1] The only certain occurrence of *O. malabarica* outside Ceylon is near Quilon in Travancore (Carter, 1857), about 200 miles west of its Ceylon occurrences. It seems certainly absent from Kach, and in Egypt the first invasion of the Indian Ocean is marked by the *Pecten-vasseli* fauna, which (as no trace of it has been found in Ceylon) probably belongs to a later date than *O. malabarica.*

The identity of the Quilon beds with those of Northern Ceylon can hardly be doubted. In addition to *O. malabarica*, Carter recorded a few gastropods, all identified with species from Kach or Sind. Only one of these, *Cerithium rude*, appears also on our list; another is given by Fedden as a pre-Gaj form, and the remainder are not dated by him at all. Though the gastropods do not go far, therefore, to support the evidence of the foraminifer, they do not traverse it; and large foraminifera are generally more restricted in range, and therefore more useful for dating, than gastropods.

The other marine Neogene fauna to which we naturally look for comparison is that of Karikal, on the Coromandel coast, about 80 miles almost due north of Kirimalai. The gastropods of this fauna, which are beautifully preserved, have been described by Dr. Cossmann (1900–03–10). It is rather surprising that, in only very few cases, can any of the Karikal species be even approximately identified in Ceylon, and on the other hand that such striking forms as the large *Conus brevis* should apparently be wanting at Karikal. The Karikal fauna is regarded by Dr. Cossmann as Pliocene; but Vredenburg, in his diagram of the evolution of the Indian Ocean fauna (1912) placed it on the level of the Upper Hinglaj (Vindobonian). To us it appears to be probably separated from the *Orbiculina-malabarica* Beds by a gap wider than that between the latter and the *Ostrea-virleti* Beds of Southern Ceylon. If these last be Vindobonian and probably Upper Vindobonian (Tortonian), the *O.-malabarica* Beds must be,

[1] The limestone of Minihagalkanda contains foraminifera which, when more fully studied, may help in the more exact determination of its age. Owing to the compact nature of the rock, only chance sections can be studied; and, in view of the already long delay in the completion of this paper, it did not seem wise to wait for a complete series of sections of the available material.

at the earliest, very late Vindobonian, and may be as late as Pontian (or rather Sahelian, as they are marine), while the Karikal beds could not be earlier than Pliocene.

[POSTSCRIPT. I am indebted to Dr. H. Sadek for information concerning the Miocene of Egypt, which suggests slight modifications in the foregoing conclusions. He has found evidence of temporary communication between the Mediterranean and Indian Oceans at two distinct dates in the Vindobonian epoch—one at its very commencement, the other much later. Oysters of the *O. virleti* type were already established in Egypt before the earlier of these connexions, in late Burdigalian times, and they range to the local summit of the Vindobonian. It would, therefore, seem more probable that *O. virleti* migrated from Mediterranean to Indo-Pacific areas than *vice versâ*. At the same time, the date of the Minihagalkanda beds becomes a little less certain. While the negative evidence of the foraminifera would seem to exclude any probability of a Burdigalian date, they may belong to the opening of the Vindobonian epoch, instead of to the later date within it suggested above.—A. M. D., *October 25th, 1923.*]

Palæontological Details.

ORBICULINA MALABARICA (H. J. Carter). (Pl. XXVIII, figs. 1–4.)

1853. *Orbitolites malabarica* H. J. Carter, Ann. Mag. Nat. Hist. ser. 2, vol. xi, p. 425 & pl. xvi B, figs. 1–4.
1856. A fossil *Orbiculina* W. B. Carpenter, Phil. Trans. Royal Soc. vol. cxlvi, p. 549 & pl. xxviii, figs. 17–19.
1902. *Orbiculina malabarica* H. Douvillé, Bull. Soc. Géol. France, ser. 4, vol. ii, pp. 300–301.

Compare also :—

1917. *Orbiculina* cf. *adunca* Fichtel & Moll, Martin, Samml. Geol. Reichs-Mus. Leiden, n. s. vol. ii, pt. 7, p. 277 & pl. v, fig. 142 (Miocene of Java).

Test (plasmostracum) discoidal, thin; maximum diameter observed=21 mm.; thickness=0·75 mm. Cyclical growth not fully attained until a diameter of 3 to 5 mm. is reached. Large forms probably all microspheric; largest observed diameter of megalospheric form=5·5 mm. Diameter of megalosphere=0·33 mm.; diameter of spiral passage around megalosphere=0·06 mm. Microsphere not certainly seen.

The mode of shell-growth is that typical of the genus, and has been fully described by Carpenter. From the recent type-species *O. adunca* Fichtel & Moll, it is readily distinguished by its large size, and the perfect cyclical growth of the greater part of the disc, despite the more prolonged period of spiral growth. From the Miocene form described by Martin from Java it differs in exactly the opposite way, in having spiral growth restricted to early life instead of continuing throughout life (or at least up

to 12 mm. in diameter). It is interesting to note that a single specimen of what seems to be Martin's species was found attached to a *Clypeaster depressus* (Brit. Mus. E 16588) at Minihagalkanda, where *O. malabarica* does not occur.

The type-locality of this species having been more than once incorrectly given, it is restated here on the authority of the Annual Report of the Geological Survey of India for 1883 (Rec. G. S. India, vol. xvii, p. 9).

Age.—Miocene (Vindobonian or later).

Type-locality.—Purappakkara, about 7 miles north-west of Quilon, Travancore (at a depth of 40 feet, under laterite).

Ceylon localities: Kirimalai and near Pallai, Jaffna peninsula; north of Pomparippu (North-Western Province); Puttalam (North-Western Province).

CLYPEASTER sp., aff. CARTERI Duncan & Sladen. (Pl. XXIX, figs. 1 & 2.)

1883. *Clypeaster carteri* P. M. Duncan & W. P. Sladen, 'Tertiary Fossil Echinoidea of Kachh & Kattywar' Palæontologia Indica, ser. 7 & 14, vol. i, pt. 4, p. 49 & pl. xii, fig. 12.

Compare also:—

1840. *Clypeaster oblongus* J. de C. Sowerby, in Grant, Trans. Geol. Soc. ser. 2, vol. v, pt. 2, p. 327 & pl. xxiv, figs. 25–25 *a*.

The Ceylon species differs from *C. carteri* (1) in outline, (2) in the details of the pore-fields.

(1) The postero-lateral margins are much more oblique, bringing the postero-lateral angles on a level with the posterior end of the petals, instead of well behind them.

(2) The costæ carry a few small tubercles, instead of only granules; and in the odd ambulacrum the pore-fields are not quite as broad as the inter-poriferous area.

It is probable that there are other small differences, but they cannot be definitely stated from the description and solitary figure of *C. carteri*. The Ceylon specimen is perfect, and shows a typical clypeastroid apex, with central madreporite and five genital pores.

The type of *C. oblongus* Sowerby is a broken specimen. So far as can be determined, its proportions are very much the same as those of the Ceylon specimen, and it diverges even more than the latter from *C. carteri* in respect of its costæ, which have often five tubercles, while those of the Ceylon specimen rarely have as many as four.

According to the account given by Duncan & Sladen, *C. carteri* should be Oligocene, but Vredenburg has warned us as to the confusion of horizons by those authors.

Age.—Miocene (Vindobonian).

Locality.—Minihagalkanda, Southern Province (Ceylon).

Pinna pachyostraca sp. nov. (Pl. XXIX, figs. 3 & 4.)

1836. ? An *Pinna nobilis* Deshayes, in 'Expédition Scientifique de Morée' vol. iii, p. 113.

This species is represented only by a large fragment of the right valve, with a portion of the edge of the associated left valve (the holotype—Brit. Mus. L. 28743) and by three small fragments (L. 28744). Nevertheless, it shows features so distinctive that a new specific name appears justifiable.

Shell deltoidal, with acuminate umbo (probably very similar in outline to the recent *Atrina nigra* Chemnitz sp.). Dorsal and antero-ventral margins diverging, in the part preserved, at an angle of 65°, this angle becoming more acute towards the apex. Antero-ventral and postero-dorsal sectors about equal, the former marked only by growth-lines, the latter bearing six coarse costæ, increasing to seven by intercalation of an extra costa in the middle of the sector, at a distance of, probably, about 65 mm. from the apex (with probable further increases beyond, one of the fragments showing five costæ in a space of 42 mm.). Test prismatic, very thick, especially towards the antero-ventral margin, varying from 1 to 9 mm. in the holotype, but attaining 14 mm. in one of the smaller fragments (Pl. XXIX, fig. 3). The costæ are solid thickenings of the test, and do not show on the interior.

I refer this species to the genus *Pinna* (although it is quite likely that it may really be an *Atrina*), on the principle that, in a case of uncertainty, it is better to use the more familiar designation.

It is not impossible that the fragments of a very thick-shelled *Pinna*, described by Deshayes from the same series of beds as *Ostrea virleti* in Greece, belong to this species. The fragments were evidently not good enough to be figured, and Deshayes only referred them, with great doubt, to *P. nobilis*, because that was the characteristic species of the adjacent seas. In the 2nd Mediterranean stage of the Vienna Basin, however, *Pinna brocchii* A. d'Orbigny has a thickness of 2·5 to 8 mm. according to Hœrnes, and the Greek fragments may belong to that species.

Age.—Miocene (Vindobonian).

Locality.—Minihagalkanda, Southern Province (Ceylon).

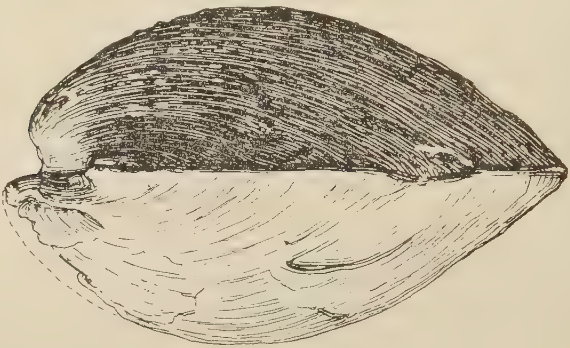
Spondylus waylandi sp. nov. (Pl. XXIX, fig. 5, and text-figs. 2–3, p. 594.)

Inflated-lenticular, approaching globose: profile of valves passing from strongly convex to slightly concave near the margins. Slightly inequivalve; distinctly inequilateral. Height and length approximately equal, thickness=3/5 of the other dimensions. Maximum measurements=approximately 75 mm., 75 mm., 45 mm. Height of the left valve=about 14/15 that of the right valve. Horizontal distance of umbo from the anterior end=about 9/10 of its distance from the posterior end.

Ears distinct; cardinal area very small, and difficult to expose.

Surface ornamented alike on both valves with close-set, semicylindrical, scaly costæ. At a distance of 30 mm. from the umbo there are five costæ in every 6 mm. The costæ increase in number by occasional intercalations, and, at any level, about a third of the costæ, irregularly distributed, are distinctly smaller than

3.



[View from the anterior end.]

2.

[View from the left side.]

Figs. 2 & 3.—Spondylus waylandi *sp. nov., holotype (Brit. Mus. L. 28750). Natural size. Miocene, Minihagalkandu (Ceylon).*

the others, being of late intercalation. In well-preserved parts, fine longitudinal striæ may be seen both on the costæ and in the hollows between them. At intervals of from 1·5 to 3 mm. (the shorter intervals being on the smaller costæ) each costa rises into a short thick scale, sometimes semitubular in form.

Although all the specimens are imperfect, I select one (Brit. Mus. L. 28750) as a holotype, the other six (L. 28751–56) being paratypes.

This is one of a small group of species in which there is only partial development of the most characteristic features of the genus *Spondylus*—the great size of the cardinal area, especially in the right valve; the wide separation of the umbones; the strongly inequivalve character; the diversity of the ornament on the two valves. As all these features are obviously adaptations to the sessile habit, the species which show them but feebly are simply a group of less specialized forms, and do not necessarily possess any such close mutual relationship as would be implied by the separation of them as a sub-genus or section. Among these species are the recent *S. imperialis* Chenu, also recorded as a fossil from Java, and the Sind fossils *S. rouaulti* and *S. tallavignesi* A. & H., which all agree in having at intervals strong ribs with a greater development of spines. These may possibly form a genetic series, but the spiny character is much more fully developed in the first-named species. *S. waylandi* differs from these in the more uniform character of the ribs. Fuchs (in Zittel, 1883) figured two imperfectly preserved *Spondyli* from Siwa, which present decided resemblances to *S. waylandi*. His *Spondylus* sp. (pl. viii, figs. 7 & 8) is smaller, narrower and thicker, and more decidedly globose, but the ribbing seems to be very similar; while his *S.* sp. cf. *crassicostatus* (pl. viii, fig. 13 *non* 14) seems to have the inflated-lenticular form, but is rather narrower, and there is a suggestion on the cast of an alternation of one strong with several weak ribs.

Age.—Miocene, Vindobonian.

Type-locality.—Minihagalkanda, Southern Province (Ceylon).

AMUSIUM SUBCORNEUM (A. d'Archiac & J. Haime).

1853. *Pecten corneus* A. d'Archaic & J. Haime, *non* J. Sowerby, 1818; 'Description des Animaux Fossiles du Groupe Nummulitique de l'Inde' p. 269 & pl. xxiii, figs. 10 *a*, *b*, *c*, 11.

Although the four specimens from Minihagalkanda are all imperfect, there can be little doubt as to their identity with the species of d'Archiac & Haime. Those authors, while referring their Sind specimens to *Pecten corneus* Sowerby, were very doubtful of that reference, on account of the smooth exterior and radially marked interior. Therefore they proposed the trivial name *subcorneus*, in case of need. These characters which distinguish the Sind species from *P. corneus* are not simply specific but generic, being the distinctive features of *Amusium*.

Of the recent species of *Amusium* (all Indo-Pacific) the fossil form is nearest to *A. japonicum* (Gmelin); while it is also comparable with *A. placunoides* (K. Martin) from the Rembang (Older Miocene) of Java, and Burdigalian of the Andaman Islands. From both these species it appears to differ in the closer crowding

of the internal ribs. It seems advisable, therefore, to distinguish it by the trivial name suggested by A. d'Archiac & Haime, and approved by Fedden in his 1879 list.

Ostrea virleti Deshayes. (Text-figs. 4–7, pp. 597, 598.)

1836. *Ostrea virleti* Deshayes, in 'Expédition Scientifique de Morée' vol. iii, p. 123 & pl. xxi, figs. 1–2.
1859. *Ostrea virleti* H. Abich, 'Das Steinsalz & seine Geologische Stellung im Russischen Armenien' Mém. Acad. Imp. Sci. St. Pétersb. ser. 6, vol. vii [ix], p. 124 & pl. iii, fig. 1, pl. v, figs. 1, 2.
1883. *Ostrea virleti* Th. Fuchs in Zittel, 'Beiträge zur Geologie & Palaontologie der Libyschen Wüste' Palæontographica, vol. xxx, Pal. Theil, pp. 43, 61, pls. iv & v.
1899. *Ostrea (Alectryonia) virleti* R. B. Newton, Geol. Mag. p. 205.
1901. *Ostrea peguensis* F. Nœtling, 'Fauna of the Miocene Beds of Burma' Pal. Ind. n. s. vol. i, pt. 3, p. 107 & pl. ii, figs. 1–2 *b*.

Other comparable species :—

1847. *Ostrea crassicostata* G. B. Sowerby, in J. Smith, Q. J. G. S. vol. iii, p. 420 & pl. xix, fig. 23. (Miocene of Portugal.)
1855. *Ostrea vespertina* Conrad, 'Pacific Railroad Report' [reprinted in U.S. Geol. Surv. Prof. Paper 59, 1909, App. VI]. (Newer Miocene of California.)
1909. *Ostrea djuvanaensis* K. Martin, 'Die Fossilien von Java' Samml. Geol. Reichs-Mus. Leiden, n.s. vol. i, pt. 2, p. 334 & pl. xlvi, figs. 1–4. (Older Miocene of Java.)

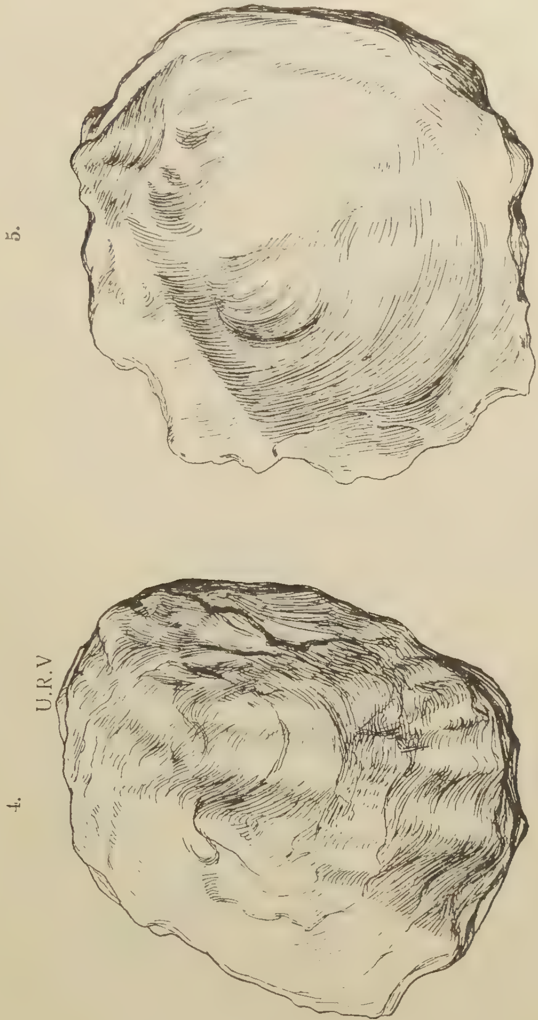
This species is represented by six specimens from Minihagalkanda (Brit. Mus. L. 28757–62), three consisting of both valves inseparably united in the natural position, and three of left valves only. They show considerable variation in form and proportions, and are all somewhat smaller than any of the figured specimens, but agree with those and one another in having few, coarse, angular ribs, occasionally bifurcating, and somewhat unevenly distributed over the surface: ribs on one valve answering to sulci on the other. Some of the specimens (particularly L. 28757, fig. 4) closely resemble Nœtling's figures, others are more like the Egyptian specimens. Most of them show, in greater or less degree, a tendency to obliquely posterior elongation (as compared with the Greek and Egyptian specimens), and in one case (L. 28759, figs. 6 & 7) this is combined with the development of what is practically a posterior ear: the form then approaches that of *O. crassicostata* from the Miocene of Portugal.

The ligamental area is rather large and obtusely triangular: it does not attain the great size shown in some of the Siwa specimens, possibly because the Ceylon specimens are not full-grown or are less gerontic. It is sometimes inclined towards the posterior end. On the interior of the left valve there is a tendency to the formation of two pits (fig. 5, p. 597), like those shown in Fuchs's pl. iv, fig. 3, and less distinctly in other Siwa figures.

The type-specimens of *O. virleti* should be in the Deshayes Collection at the École des Mines, Paris; but I was unable to find them in the course of a short visit.

The age and distribution of this species have been discussed in the general part of this paper (p. 588).

It is sometimes assigned to the genus *Lopha* or *Alectryonia*, of which the genotype is *Mytilus cristagalli* Chemnitz, but



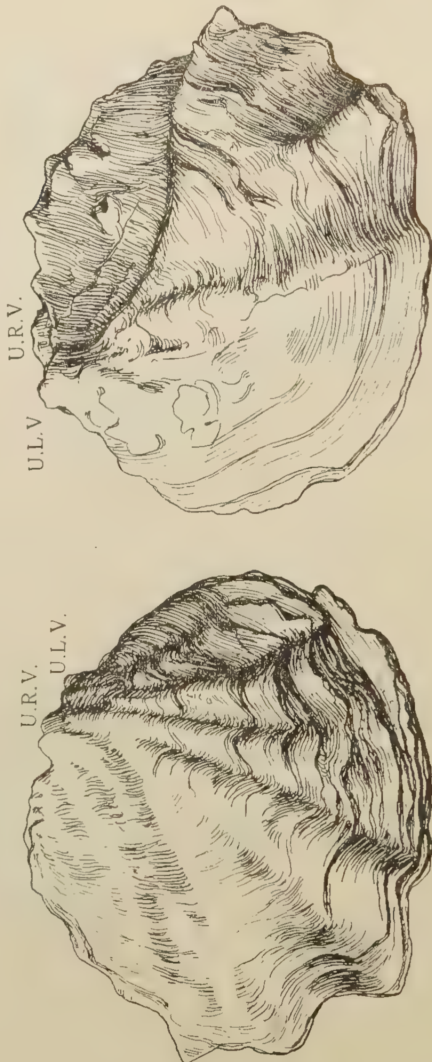
Figs. 4 & 5.—Ostrea virleti *Deshayes, from the Miocene of Minihagalkanda (Ceylon). Natural size.*

[Brit. Mus. L. 28757. Form resembling *Ostrea peguensis* Nœtling. Left valve. U.R.V.—umbo of right valve.]

[Brit. Mus. L. 28758. Interior of left valve.]

which, as usually understood, appears to me to be a very polyphyletic 'genus'. The same criticism may quite fairly be passed on the 'genus' *Ostrea*; but, where neither of two names is satisfactory, it is better to use that which is more familiar.

Of comparable species, *Ostrea vespertina* Conrad, from beds of approximately the same age in California, to judge from R. Arnold's figure (Bull. U.S. Geol. Surv. 398, 1910, pl. xlvi,



6. Right valve. 7. Left valve.

Figs. 6 & 7.—Ostrea virleti Deshayes, *from the Miocene of Minihagalkanda (Ceylon). Natural size.*

[Brit. Mus. L. 28759. Form approaching that of *Ostrea crassicostata* G. B. Sowerby.]
U.R.V.= umbo of right valve. U.L.V.= umbo of left valve.

figs. 4–5), is almost identical; *O. djuvanaensis* Martin, from the Older Miocene (Rembang Beds) of Java, differs in its strongly saddle-shaped character.

CHIONE (OMPHALOCLATHRUM) GRANOSA (J. de C. Sowerby).

1840. *Venus granosa* J. de C. Sowerby, Trans. Geol. Soc. ser. 2, vol. v, pl. xxv, fig. 7.

This species is abundant at Minihagalkanda, and is accompanied by the probably nearly related species *Venus cancellata* J. de C. Sowerby. Externally, *C. granosa* is identical in all but its slightly smaller size with the recent *Tapes denticulata* G. B. Sowerby.[1] It shows moreover close resemblance to *Dosina listeri* Gray, a recent species recorded by Martin from the Miocene of Java, and to *Venus crispata* Deshayes, also recent. It seems less close to *V. sowerbyi* Deshayes, with which Nœtling identified it. All these species may be referred to the section *Omphaloclathrum* of the genus *Chione*, despite the criticisms of Jukes-Browne,[2] if we prefer a genetic classification to one which is purely morphological.

STROMBUS spp.

Moderately small specimens of *Strombus* (35 to 45 mm. long) are very abundant at Kirimalai and fairly common at Minihagalkanda; while a single rather large specimen (nearly 80 mm.) comes from Pallai. In all these cases, unfortunately, we have only internal casts, sometimes with a little test adhering, while lumps of crystalline matrix often obscure the outline. In no case can so essential a feature as the form of the outer lip be determined. Consequently, true specific determinations are not feasible, and the fossils can only be roughly classified as follows:—

(1) With only one row of tubercles on the last whorl.

The large form from Pallai (Brit. Mus. G. 27040) resembles in outline young specimens of *S. tricornis* Lamarck, which retain the early straightness of outline of the last whorl. It also resembles the South European Helvetian *S. bonellii* Brongniart, except in not having the second row of tubercles. It is also comparable with the holotype of *S. nodosus* J. de C. Sowerby, a Kach species; but that is too badly preserved for the absence of a second row of tubercles to be asserted with complete certainty.

Several specimens from Minihagalkanda show resemblance to *S. karikalensis* Cossmann (Pliocene of Karikal), and to *S. isabella*, var. *thersites* Martin (Pliocene ?—localities Sondé and Meneng-teng—of Java), but attain a larger size (full length probably =60 mm.). One, at least, from Kirimalai shows even closer resemblance to *S. karikalensis*, and is but slightly larger.

Another Minihagalkanda specimen shows near resemblance to *S. fortisi* A. & H. (*non* Brongniart, the true *fortisi* being an Upper Eocene—Auversian—species).

[1] 'Thesaurus Conchyliorum' vol. ii (1855) p. 694 & pl. cl, fig. 114.
[2] Proc. Malac. Soc. vol. xi (1914) pp. 70–72.

(2) With two rows of tubercles.

Some at least of the abundant casts from Kirimalai show the two rows of tubercles very distinctly. But for this, they might be identified with *S. nodosus* Sowerby, which they closely resemble in shape; the holotype of that species does not seem, however, to have the second row, although the bad state of preservation makes its absence uncertain.

Two bituberculate strombs from Minihagalkanda may best be compared with *S. spinosus* Martin, from the Miocene of Java.

Semicassis spp.

Four fossils from Kirimalai are referred to the genus *Semicassis*. One of these (Brit. Mus. G. 27051) retains the test, and, although the adherence of intractable matrix somewhat obscures the shape, it agrees very closely with the recent *Semicassis booleyi* (G. B. Sowerby), from the Andaman Islands.[1] It also resembles *S. rembangensis* (Martin), a Java Miocene fossil, but is rather larger than that species.

The other three are internal casts, and therefore very difficult to name. One of them agrees in proportions with the testiferous specimen, and might be the same species; but it matches equally well with *S. phillipsi* (A. & H.), from Sind, and indeed with other fossil casts. The remaining two certainly belong to a different species, being decidedly narrower (breadth =3/5 of length instead of 4/5): they agree very well with *S. sculpta* (J. de C. Sowerby), from Kach, and also, except in their larger size, with *S.* (*Casmaria*) *bonneti* Cossmann, from Karikal.

Conus brevis J. de C. Sowerby.

In Grant, Trans. Geol. Soc. ser. 2, vol. v, pt. 2 (1840) pl. xxvi, fig. 33.

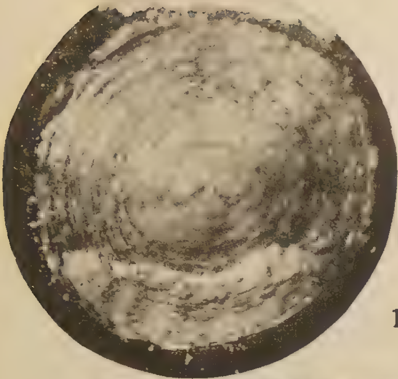
Badly preserved specimens, referred without much doubt to this Kach species, are fairly common at Minihagalkanda, where the largest measures over 100 mm. in diameter at its broadest, and was probably 150 mm. in height. But a solitary specimen from Kankesanturai, at the other extremity of the island, the only fossil recorded from that locality, is even larger, the diameter being about 160 mm. Sowerby mentions the large size which this species attains in Kach. At Kirimalai no such large form was found, and none of the small Cones can be safely referred to this species.

Literature bearing on the General Relations of the Miocene Fauna of Ceylon.

1833–36. 'Expédition Scientifique de Morée' vol. ii, pt. 2, p. 222 [Stratigraphy]; vol. iii, p. 123, & pl. xxi [Palæontology].

1840. C. W. Grant.—'Memoir to Illustrate a Geological Map of Cutch' Trans. Geol. Soc. ser. 2, vol. v, pt. 2, pp. 289–329; shells figured and described by J. de C. Sowerby, pls. xxi–xxvi.

[1] Journ. Malacol. vol. vii (1900) pp. 162–63, text-fig.



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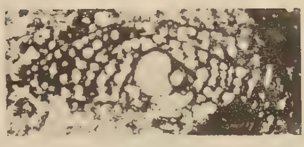

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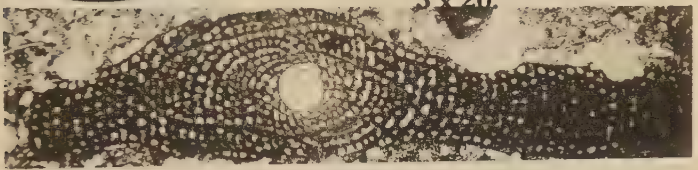

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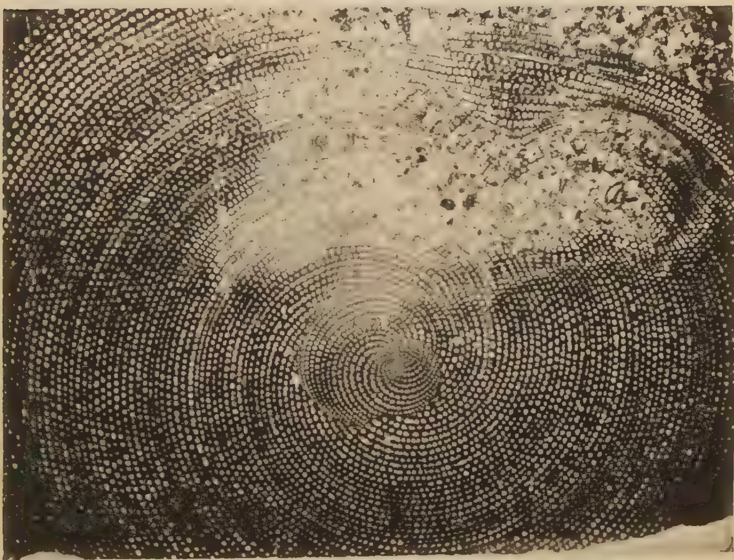
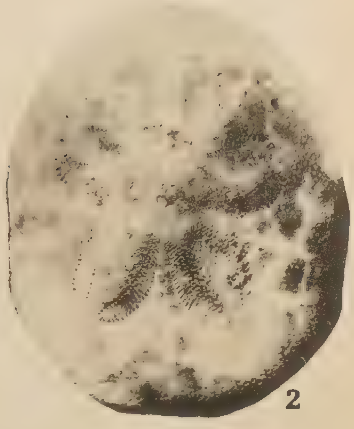


A.M.D. PHOTO.

ORBICULINA MALABARICA (CARTER).

1



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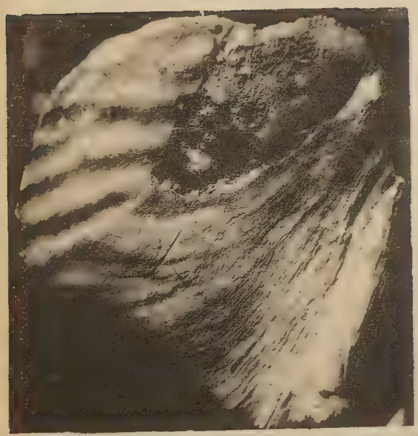

4 x ½.

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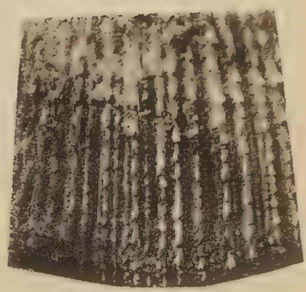


A.M.D. PHOTO.

MIOCENE FOSSILS, MINIHAGALKANDA (CEYLON).

1853. E. J. A. D'Archiac & J. Haime.—'Description des Animaux Fossiles du Groupe Nummulitique de l'Inde.'
1857. H. J. Carter.—Journ. Bombay Branch, Roy. Asiatic Soc. vol. v, p. 301; and 'Geological Papers on Western India' pp. 740, 743.
1859. H. Abich.—'Das Steinsalz & seine Geologische Stellung im Russischen Armenien' Mém. Acad. Imp. Sci. St. Pétersb. ser. 6, vol. vii [ix], pp. 59–150.
1879. F. Fedden.—'On the Distribution of the Fossils described by Messrs. d'Archiac & Haime in the different Tertiary & Infra-Tertiary Groups of Sind' Mem. Geol. Surv. India, vol. xvii, pp. 197–210.
1883. K. A. Zittel, Th. Fuchs, & others.—'Beiträge zur Geologie & Paläontologie der Libyschen Wüste' Palæontographica, vol. xxx, pt. 1.
1885. E. Suess.—'Das Antlitz der Erde' vol. i, pp. 413, 414. [French ed. p. 416.]
1889. M. Bertrand & W. Kilian.—'Mission d'Andalousie' Mém. Acad. Sci. Paris, vol. xxx, no. 2, pp. 377–569.
1891–1917. K. Martin.—'Die Fossilien von Java' Samml. Geol. Reichs-Mus. Leiden.
1900. E. Haug.—'Les Géosynclinaux & les Aires Continentales' Bull. Soc. Géol. France, ser. 3, vol. xxviii, pp. 617–711.
1900–03–10. M. Cossmann.—'Faune Pliocénique de Karikal (Inde Française)' Journ. Conchyl. vol. xlviii, pp. 14–66 & pls. ii–iv; vol. li, pp. 105–73 & pls. iii–vi; vol. lviii, pp. 34–86 & pls. ii–v.
1901. F. Nœtling.—'Fauna of the Miocene Beds of Burma' Pal. Indica, n. s. vol. i, pt. 3.
1904. R. B. Newton in T. English.—'Eocene & Later Formations surrounding the Dardanelles' Q. J. G. S. vol. lx, p. 285.
1911. R. B. Newton in J. W. Gregory.—'Geology of Cyrenaica,' Q. J. G. S. vol. lxvii, pp. 597, 627.
1911. E. W. Vredenburg.—'On the Identity of *Ostrea promensis* Nœtling from the Pegu System of Burma & *Ostrea digitalina* Eichwald from the Miocene of Europe' Rec. Geol. Surv. India, vol. xli, pp. 36–41.
1911. A. F. Stahl.—'Persien' in 'Handbuch der Regionalen Geologie' vol. v, pt. 6.
1912. F. Oswald.—'Armenien' *Ibid.* vol. v, pt. 3.
1912. E. W. Vredenburg.—'Remarks on the Evolution of the Recent Marine Molluscan Fauna in the Newer Tertiary Rocks of India' Proc. Malac. Soc. vol. x, pp. 259–61 & pl. xiii.
1916. W. F. Hume.—'Report on the Oilfields Region of Egypt.'
1921. E. W. Vredenburg.—'Results of a Revision of some Portions of Dr. Nœtling's Second Monograph of the Tertiary Fauna of Burma' Rec. Geol. Surv. India, vol. li, pp. 224–302.
1921. R. B. Newton in J. W. Gregory.—'Rift-Valleys & Geology of East Africa' pp. 74, 384.

EXPLANATION OF PLATES XXVIII & XXIX.

Plate XXVIII.

Orbiculina malabarica (H. J. Carter). [See pp. 591–92.]

Fig. 1. Surface-view of a partly decorticated specimen (probably microspheric) × 2. Kirimalai, Jaffna Peninsula, Ceylon. (Brit. Mus. P. 22325.)

2. Oblique (near vertical) section of megalospheric form, × 25, showing the megalosphere with the spiral passage indenting one side. Puttalam, North-Western Province, Ceylon. (Brit. Mus. P. 22329.)

3. Oblique (near horizontal) section of a megalospheric form, × 20, showing the megalosphere and part of the spiral passage leading from it. North of Pomparippu, North-Western Province, Ceylon. (Brit. Mus. P. 22330.)

4. Horizontal section of microspheric form, × 12, Pallai. Jaffna Peninsula, Ceylon. (Brit. Mus. P. 22326.)

Plate XXIX.

Figs. 1 & 2. *Clypeaster* sp. between *carteri* Duncan & Sladen and *oblongus* J. de C. Sowerby, natural size.—Fig. 1, aboral surface; fig. 2, oral surface. Minihagalkanda, Southern Province, Ceylon. (Brit. Mus. E. 16589.) [See p. 592.]

Figs. 3 & 4. *Pinna pachyostraca* sp. nov.—Fig. 3, broken edge of a fragment (Brit. Mus. L. 28744), natural size, showing the thickness of the prismatic layer. Fig. 4, holotype (Brit. Mus. L. 28743), right valve, half of the natural size. [See p. 593.]

Fig. 5. *Spondylus waylandi* sp. nov., paratype (Brit. Mus. L. 28751), right valve, natural size, showing details of surface-ornament. [See p. 593.]

Discussion.

Sir Thomas Holland said that this precise description of a new occurrence of Miocene deposits would stimulate the Geological Survey of India to renewed search for relics of the Miocene trespass on the peninsula of India. Miocene fossils were found by Mr. G. H. Tipper twenty years ago on the Andaman Islands, and preliminary descriptions of them by Mr. E. W. Vredenburg indicated Burdigalian affinities. He asked whether Dr. Davies had been able to compare the Andaman records with the apparently younger Miocene fauna found by Mr. Wayland.

Dr. A. Morley Davies, in reply, said that he had overlooked the record of Miocene in the Andaman Islands, and was glad to have his attention called to it.

22. *The* LATE-GLACIAL STAGE *of the* LEA VALLEY (THIRD REPORT). By SAMUEL HAZZLEDINE WARREN, F.G.S. (Read February 28th, 1923.)

SHORTLY after the publication of the later of the previous papers on this subject, I discovered another exposure of the Late-Glacial deposits of the Lea Valley. It was found under rather unsatisfactory stratigraphical conditions, during some small secondary digging in a practically abandoned gravel-pit of large size. The sides of the pit are sloped down and overgrown, and in part built over, so that the stratigraphical relations of the deposit in question are obscure.

The site is on the higher margin of the 50-foot, or Taplow, Terrace, immediately below the 100-foot contour, east of the New River, and north of the road which runs through Barrowell Green, between Winchmore Hill and Palmers Green, Edmonton.

On the first visit, I noticed a bed of clay, about a foot thick, of which several yards could be seen. As it was clearly in place, and had been left as unprofitable during the digging, I took a sample home, and found it to yield seeds, but comparatively little vegetable débris apart from the seeds, so it was unusually easy to work for the purpose in hand.

A few days later I spent an afternoon in the pit, washing out as much of the clay as I could in the time, and forwarded the results to the late Mr. Clement Reid. He sent me a preliminary list and statement, which were not intended for publication until the identifications had been checked; this work Mrs. E. M. Reid & Miss M. E. J. Chandler have now kindly completed, and their enlarged list is appended. In those days of the great War one could not legitimately spend too much time on such work, and I am astonished at the comparatively long list of species obtained from a relatively small amount of material, as compared with the large quantities worked through from each of the other sections previously described.

I obtained from one of the workmen a very good Late Chellean implement, which he said that he had found at the base of the gravel in this pit at Barrowell Green; it had been reposing for some years on a rockery in his garden. It is a contemporary implement, and not a derivative; nor do I doubt his testimony, as the specimen would be normal for the corresponding situation and level at Stoke Newington. Although one could not regard this as critical evidence, I think that we may take it as tending to confirm the date which should be assigned to the deposit, according to its position and level. But, if this be correct, we are in some difficulty with the Arctic Bed, which in these circumstances ought not to be there.

There is a considerable weight of cumulative evidence for a temperate climate during Taplow Terrace times, with less frost

than we have nowadays during the earlier stage. I think that it would be unwise to put the Ponders End conditions back into any part of the Taplow Terrace group, without much more satisfactory evidence than we have here. My suggestion is that this patch of Arctic Bed represents the silting of a stream-course of Low Terrace age, which cut across the Taplow Terrace. But I could not prove this contention against criticism—I merely think it the more probable assumption.

There is evidently a spring here, as a streamlet still rises just below the level of the site. This stream has to-day a distinct, though very diminutive, valley of its own, which comes out very clearly on the Geological Survey 1-inch map of the London District (Sheet 2) immediately north and east of 'Huxley Farm', where the streamlet concerned cuts through the brick-earth down to the gravel below. There might very easily have been a small swamp here, associated with this spring and streamlet and its diminutive valley.

As a possible explanation of the occurrence of non-Arctic plants in these Arctic deposits, I would quote a fact mentioned by Prof. A. C. Seward in his lecture on Greenland to this Society: namely, that in the immediate vicinity of springs, certain plants are enabled to live far to the north of their normal habitat, owing to the warmth supplied by the spring-water. Such geological deposits as we are considering are largely fed from the neighbourhood of springs.

Appendix.—The Barrowell Green (Lea Valley) Arctic Flora. By Mrs. Eleanor Mary Reid, B.Sc., F.L.S., F.G.S., and Miss Marjorie Elizabeth Jane Chandler.

The Barrowell Green material was examined by Mr. Reid in the spring of 1916. By the request of Mr. Hazzledine Warren we have re-examined it, with the result that we have added a few new species and made a few alterations in Mr. Reid's list. In this list a species of *Cochlearia* is recorded. In other Lea-Valley deposits and in the Cam-Valley deposit fruits were found, and the determination was correct; but at Barrowell Green we have only seen seeds referred to this species, and in this case the determination was incorrect, the seeds being those of a *Cerastium* allied to *C. vulgatum* Fries, an Arctic species. It is possible, of course, that there were pods which we have not seen.

With regard to the description of this deposit, we cannot do better than quote Mr. Reid's original description from his letter of February 4th, 1916, to Mr. Warren :—

'The Barrowell Green flora certainly points to the same period as the floras of the other Lea Valley localities. It shows the same Arctic or Sub-Arctic conditions, and contains several of the same peculiar plants, such as *Silene cælata*, *Linum Præcursor*, *Salix Lapponum* and the undetermined *Cochlearia*. No doubt the list includes about a dozen species which have not yet been found at Angel Road, Hedge Lane, Ponders End, or Temple Mills; but none of these are significant species: that is to say, they are species that one

would expect to find at the other localities, if the plants from each were thoroughly known. There is nothing in the lists to distinguish the localities climatically.'

Barrowell Green Arctic Flora.	Plants reaching Arctic regions.	Plants reaching Alpine heights.	Not Arctic or Alpine.	Plants occurring in other Lea-Valley localities.	
1. *Thalictrum flavum* Linn.	+	...	...	+	
2. *Ranunculus aquatilis* Linn.	+	...	...	+	
3. *Ranunculus hederaceus* Linn.	...	+	.	+	Not seen by us.
4. *Ranunculus nemorosus* De Candolle	...	+			
5. *Ranunculus repens* Linn.	+	.		+	
6. *Caltha palustris* Linn.	+				
7. *Viola lutea* Hudson					
8. *Silene cœlata* Reid	...	...	..	+	
9. *Cerastium* sp., cf. *vulgatum* Fries.	+				
10. *Linum Præcursor* Reid	...	.	.	+	
11. *Spiræa Ulmaria* Linn.	+	.	...	+	
12. *Potentilla Anserina* Linn.	+	...	...	+	
13. *Potentilla nivalis* Lapeyrouse	...	+			
14. *Potentilla erecta* Hampe	+	...		+	
15. *Hippuris vulgaris* Linn.	+	...	.	+	
16. *Myriophyllum spicatum* Linn.	+	...	.	+	
17. *Apium nodiflorum* Reichberg	...	.	+	...	Not seen by us.
18. *Valeriana dioica* Linn.					
19. *Carduus heterophyllus* Willd.	+				
20. *Sonchus* sp.					
21. *Taraxacum* sp.	?	?	?	+	
22. *Arctostaphylos Uva-ursi* Spreng.	+				1 specimen, large, perhaps owing to bursting and flattening, other of recent size; ornamentation coarser and more complex.
23. *Primula farinosa* Linn. (?)	+	+	..	..	
24. *Galeopsis* sp.					
25. *Littorella* sp.					
26. *Atriplex patula* Linn.	+				
27. *Chenopodium* sp.					
28. *Polygonum aviculare* Linn.	+	...	..	+	
29. *Salix herbacea* Linn. (?)	+	+	...	+	Only a leaf-tip seen by us. If this was the only evidence, it seems to us insufficient.
30. *Salix Lapponum* Linn. (?)	+	+	...	+	
31. *Juniperus* sp.					
32. *Sparganium minimum* Fries.	...	..	...	+	
33. *Sparganium natans* Linn.	+				
34. *Alisma Plantago* Linn.	+	..	...	+	
35. *Potamogeton crispus* Linn.	...		+	+	
36. *Potamogeton* cf. *densus* Linn.	...	...	+		
37. *Potamogeton filiformis* Nolte	+				
38. *Potamogeton natans* Linn.	..	...	+		
39. *Potamogeton pectinatus* Linn.	+				
40. *Potamogeton polygonifolius* Pourr.	...	...	+		
41. *Potamogeton* sp.					
42. *Eleocharis uniglumis* Link					
43. *Scirpus lacustris* Linn.	+				
44. *Carex dioica* Linn.	+				
45. *Carex leporina* Linn. (?)	+				
46. *Carex punctata* Gaud.	...				
47. *Carex rostrata* Good.	+				
48. *Isoetes lacustris* Linn.	+	...	...	+	

[For the Discussion, see p. 634.]

23. *The* ELEPHAS-ANTIQUUS BED *of* CLACTON-ON-SEA (ESSEX) *and its* FLORA *and* FAUNA. By SAMUEL HAZZLEDINE WARREN, F.G.S. (Read February 28th, 1923.)

THE elephant-remains from the Pleistocene deposits of the Essex coast have attracted interest and curiosity which can be traced back to the twelfth century, during the reign of Richard the First.

Camden's '*Britannia*' of 1610 refers as follows to the remains from Walton-on-the-Naze:—

'What hath been found in this place, have heere out of the words and credit of Ralphe, the Monke of Coggeshall, who wrot 350 years agoe: "In King Richard's time, on the sea-shore, at a village called Erdulphnesse [Walton-on-the-Naze], were found two teeth of a certain Giant, of such a huge bignesse, that two hundred such teeth as men have now a daies might be cut out of them. These I saw at Coggeshall."'

In 1803 a fall in the low cliff, at about a mile south-south-west of the Naze, exposed to view a skeleton described as being 30 feet long, and having molars weighing 7 and 12 pounds each.[1]

I have never seen the Walton deposit, which is now permanently buried under a considerable accumulation of sand; but it is quite probable that some temporary excavation, or exceptional storm, may again expose it to view.

I am not aware of any reference to the elephant-bed of Clacton prior to that made by John Brown, of Stanway, in the Magazine of Natural History for 1838 (n.s. vol. ii, p. 163).

The eastern end of Essex is occupied by a nearly level plateau, with a very gentle slope towards the sea, trenched by a series of river-valleys. On this plateau, between the levels of 70 and 85 feet O.D., there are the remains of river-gravels, often much contorted, with Chellean implements. The most significant feature of these gravels, to my mind, lies in the abundance of Lower Greensand chert which they contain.[2] It seems impossible to doubt that they are remnants of the 100-foot, or Boyne, Terrace of the main Thames-Medway river, and are not the gravels of local streams.

The river-gravels at lower levels, with their associated elephant-beds, belong, however, not to the main river, but to the tributary streams which trench the wide Boyne Terrace plateau, and now have their outlet directly into the sea. Reasons will be given later for concluding that, during the 50-foot (or Taplow) Terrace age, the main valley off the present coast of Essex had been trenched

[1] See 'The Essex Naturalist' vol. xiii (1904) p. 295.

[2] This was written some time ago, before I had seen the paper by Prof. J. W. Gregory on the 'Evolution of the Essex Rivers & of the Lower Thames' (Colchester, Benham & Co., 1922). He, too, lays stress on the abundance of the Lower Greensand chert from Kent in the gravels of the Essex coast, although I am unable to agree with his suggestion that they are Pliocene and represent the river-gravels of Walton-Crag age.

to a very considerable depth. That is to say, that after Boyne times the river was rejuvenated, and its fall became relatively very much more rapid than it had been before.

The Taplow Terrace group of deposits covers a considerable period of time, and includes quite notable changes in the river itself, in the river-deposits, and in the fauna. The earlier Taplow deposits seem much nearer to the later Boyne deposits than they are to the later deposits of the Taplow stage. I sometimes wonder whether we have not rather overlooked one of the essential conditions of river-terraces. If one stands on the flood-plain of a river, one is always told to look across to the other flood-plain on the opposite side, and to note the corresponding terrace on each side; but it is at least equally important to look in imagination through the water, and to note the difference in level between the contemporary deposits of the river-bed and the flood-plain.

At Stoke Newington the river-bank of Taplow times abuts against the Boyne Terrace, at a level of about 100 feet O.D. At Grays, the Boyne Terrace still maintains much the same level, but the Taplow Terrace has dropped nearly 50 feet. At Shoeburyness the *Corbicula* Beds of the Taplow Terrace are found below the level of low tide. This relatively rapid fall of the Taplow Terrace gives us the key to the position of the Clacton bed.

One should consider the relative dating of these Taplow deposits a little more closely, as they must come into comparison with the Clacton bed. The basement-gravel at Stoke Newington yields contemporary implements of the Late Chellean stage: that is to say, it was the river-bed at the time when much of the Boyne Terrace deposits were laid down on the flood-plain. The higher portion of the Stoke Newington deposits yields a well characterized Mousterian industry and fauna, as first shown by the late Worthington G. Smith.

The Grays deposits are divided palæontologically into two groups, although it is noteworthy that both occur at the same level, so the active period of river-erosion had then been arrested. The earlier group (Little Thurrock) consists of the classical *Corbicula* and *Hippopotamus* Beds; while the basement-gravel of the later group (West Thurrock) yields an abundant proto-Mousterian industry, characterized by the familiar 'tortoise-cores' and Levallois flakes, and is closely succeeded in the overlying beds by the *Elephas-primigenius* fauna.

Following upon the above-mentioned suggestion of arrested erosion at Grays, which would scarcely be conclusive in itself, we have irrefragable evidence at Clacton, supported by contributory evidences elsewhere,[1] of a reversal of the movement, and of the invasion of the area by estuarine conditions.

From the above outline of the facts, one may, I think, feel justified in narrowing down the correlation between the river-

[1] See the Report on the Mollusca by Mr. A. S. Kennard & Mr. B. B. Woodward, appended to the present paper, p. 633.

terraces, the human industries, the fauna, and the earth-movements, to a fairly small margin of error.

The coast from Holland to Clacton, a distance of 3 or 4 miles, is occupied by a continuous sheet of Taplow Terrace gravel. Both the base-level and the surface-level vary in different places; but, generally speaking, the mass of the gravel lies between 15 and 50 feet O.D., below and above. I have had no success in finding either human implements or any fauna in this sheet.

The Clacton elephant-bed is closely associated with the Holland sheet of gravel; but I have never seen a section that clearly showed the junction. The two are of totally different character, the Holland sheet being a cleanly washed, strongly stratified, torrential sheet of gravel and sand; while the elephant-bed represents the silting-up of a stagnant backwater, into which drifted and settled all the lighter débris of mud, wood, shells, and bones.

CORRELATION OF LOWER THAMES VALLEY DRIFTS.

Terraces.	Fauna.	Human industries.		Physical conditions.	Climate.
Boyne.	*E. antiquus.*	Chellean		Base-level.	Warm.
Late Boyne and Early Taplow.	Do. Do.	Late Chellean and Early Acheulian	Mesvinian.	Rejuvenation.	Temperate.
				Arrest.	
Mid Taplow.	Mixed.	Late Acheulian.	Proto-Mousterian.		
Late Taplow.	*E. primigenius.*		Mousterian.	Submergence.	Colder.
				Rejuvenation.	
Ponders End.	Do.				
				Further rejuvenation.	Arctic.
Buried Channel	Do.				Temperate (?).
				Submergence.	

Several contiguous bones are sometimes found together in the position of life. Possibly this silting-up may be correlated with the first setting-in of submergence, and the arrest of active erosion noted at Grays.

I am indebted to Mr. Guy Maynard for a copy of a manuscript section of the Essex coast, preserved in the Saffron Walden Museum, and believed to be by the hand of J. Brown, of Stanway, the pioneer of Essex Pleistocene Geology. This would appear to indicate the Holland Gravel as passing continuously over the elephant-bed; but the section is too crude and sketchy to be reliable.

The Rev. Osmond Fisher[1] and Mr. W. H. Dalton[2] give

[1] Geol. Mag. vol. v (1868) p. 213.

[2] 'The Geology of the Neighbourhood of Colchester' Mem. Geol. Surv. 1880, p. 9–10.

sections of the cliff as seen by them in 1868 and 1875 respectively. These differ slightly the one from the other, and both leave something to be desired in clearing up all points of detail; but, from them and from what I have been able to see myself from time to time, it is perfectly clear that the elephant-bed occupies a channel which was cut through the Holland Gravel (bed C in fig. 1, p. 610), although it may not be separated from it by any long interval of time. This channel exceeded 50 feet in depth, and had a very steep bank on the eastern side, like a channel quickly cut and quickly filled before the sides had time to break down. The late Clement Reid, without being acquainted with the locality, was able to reach the conclusion that the flora indicated a small stream flowing between dry-soil gravel-banks, and yielding no indication of the proximity of the sea.

The Holland Brook rises near Manningtree, and has a course of about 10 miles. Its valley lies to the north of the site here described. On the other side the River Colne is much larger, and has a longer course through Halstead and Colchester. The Clacton stream was quite a minor tributary, which flowed into one or other of these valleys (probably the Colne), or even directly into the main river, and merely cut a temporary channel without widening out into a valley.

Good partial exposures of different parts of the elephant-bed of the foreshore were seen from time to time between the years 1912 and 1916, and a plan was kept of their position: from this I have pieced together a fairly complete succession, but it was never all seen at one time. The basement-bed, which rests upon the London Clay, sweeps across the beach in a wide curve, with a diameter of nearly 1500 feet under the parade-wall. This, of course, is a section across the old river-bed; and the basement-bed disappears far beneath low-water at the deepest part. I have collected from bed *y* by digging under water at low tide, and the remains that came up still proved to be exclusively freshwater.[1]

My own observations have been mainly concentrated upon the elephant-bed of the foreshore, while the more detailed stratigraphical sections previously published have dealt mostly with the cliff-section, now much obscured.

The best published section of the Clacton bed by J. Brown, of Stanway, is in the Magazine of Natural History for 1840 (p. 199); while (as I have already stated) a manuscript copy of the same section is preserved in the Saffron Walden Museum. The latter adds the thicknesses of the beds as then exposed. Variants of the same section have been published by Richard Owen,[2] Osmond Fisher, and in the Geological Survey Memoir; but these do not add to the information, and most of them introduce errors of their own. Putting together the information derived from the two best sections enumerated above, we have:—

[1] These collections are marked *y** in the accompanying Appendices.
[2] 'History of British Fossil Mammals & Birds' 1846, pp. 381–82.

Fig. 1.—*Section of the West Cliff at Clacton-on-Sea.*

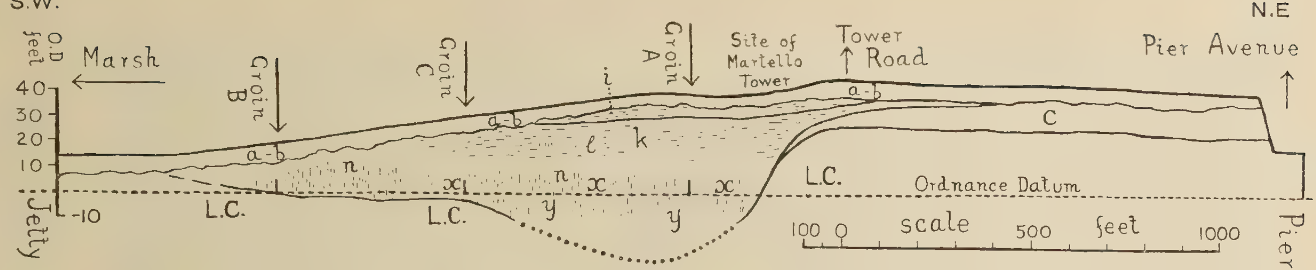
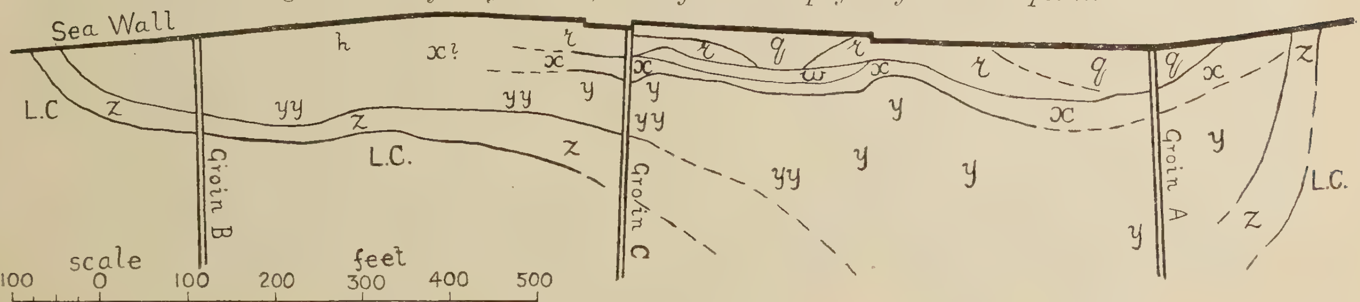


Fig. 2.—*Plan of the foreshore, showing the outcrop of the fluviatile deposits.*



[a–b=Humus, loam, and Trail. C=The Holland sheet of gravel. i=Estuarine loamy sands.
k=Estuarine 'Peaty Shale.' l=Freshwater seam in k. n=Stratified sands, with *Unio littoralis*, etc.
q–z=The fluviatile series of the foreshore, see p. 611. L.C.=London Clay.

Groynes A, B, C are permanent groynes in the order of their construction groyne A is sometimes called the 'Palace Groyne.']

	Thickness in feet.
Soil.	
1. Loam, or loamy gravel and sand, with interspersed flints, both rounded and angular; white quartz-pebbles and quartz-sandstone in boulders	6 to 7
2. Freshwater [an error for 'estuarine'] shells in red sand...... [the scale of the section indicates	1½]
3. 'Peat' or 'lignite'	10 to 12
4. Marine and freshwater shells in red sand (one of the copies adds '8 feet above high-water mark') [apparently.........	1]
5. 'Peat' or 'lignite', with subordinate and interrupted [= lenticular] beds of marine and freshwater shells. Incisor of Water-Rat. [The Saffron Walden section depicts two separate beds of 'lignite', with one bed of red sand and shells between them]	7 to 9
6. Red sand, with marine and freshwater shells. (The J. Brown correspondence, 'Essex Naturalist' vol. xix, 1920, p. 139, gives this bed as 3 feet above high-water mark) [apparently	1]
7. [The elephant-bed.] Bones of the larger mammals, generally found between the cliff and low-water mark. freshwater shells, trunks of trees, nuts and seeds, etc.	

At the present time, the cliff-sections are much weathered and overgrown; but, occasionally, useful exposures may be seen when 'cliff improvements' of various kinds are being carried out. Thus I have been able to confirm the correctness of the observations of Osmond Fisher and Mr. W. H. Dalton that Bed 2 of J. Brown's section is not freshwater but estuarine, with abundance of stunted forms of marine mollusca. It is remarkable that *Corbicula fluminalis* occurs in this bed as a derivative, although it is not known from the elephant-bed proper. I have not found estuarine or marine shells below Bed 2; but I do not cast any doubt upon the accuracy of previous observations. Adding my own observations, and abbreviating those already given, we have, as shown in figs. 1 & 2 (p. 610):—

a. Surface humus.
b. Trail; irregular loamy gravel; up to 6 feet.
i. Estuarine series, consisting mainly of red sandy beds; up to 6 feet.
k. Hard clay (= 'Peat,' 'Lignite,' and 'Estuarine Peaty Shale'), occupying the lower part of the cliff above the parade, with lenticular shelly beds, and bed *l*: up to 20 feet.
l. [Red sand and shells, a little above high-water mark; 1 foot, according to the older observers.[1]]
n–z. Elephant-bed, upper part obscured by the sea-wall. Below the sea-wall the foreshore exhibits:—
- *q*. Hard blue clay, filling channels in *r*.
  (line of erosion)
- *r*. Red and grey sandy loam.
- *w*. Fine, compact, green loam, with large concretions.
- *x*. Blue sandy loam, with much wood, including the 'nut-bed'.
- *y*. Dark sand and sandy loam. with subangular peat-stained flints, passing almost into gravel.
- *yy*. Lower part of *y*, cemented into a ferruginous and calcareous pan.
- *z*. Basement-bed, consisting of septaria and flints in blue clay.

L.C. London Clay.

[1] This part of the section is not clear to me, so I have drawn no boundary between *k* and *n* in the section. At *p* in fig. 2 there was rather mixed material, apparently the remains of a cliff landslip.

Mr. H. Picton[1] has also published a section taken near the eastern margin of the channel (east of groyne A), where the beds are becoming attenuated. His layer No. 1 of dark stiff clay = my bed *q*, and although he says 'without shells,' many shells may be collected from it in places. I should ignore 2 and 3 as a mere parting between the thicker beds. Layer 4, of blue loam = my *x*; this, Mr. Picton says, rests directly upon the London Clay (and thus completely overlaps *y*) a little to the east of the site of his section. Layer 5 I should again ignore. Layer 6, 'sand, shells, and broken flints' from 3 to 5 inches thick, is the feather-edge of my bed *y*. In the centre of the channel, the outcrop of this bed on the foreshore extends from half-tide level to far below the level of the lowest tides.

The Clacton bed is situated on the present western margin of the Holland gravel-terrace, and the surface-level slopes from 47 to 48 feet O.D. down to the salt-marshes, over the site of the elephant-bed, which originally had the gravel-banks on each side.

The hard clay (*k*) is represented in the previously published sections as overlapping the eastern gravel-bank of the old stream, but as being (at this spot) again overlain by more stratified sand and gravel. I think the latter must belong to the estuarine series, which I have seen up to 6 feet in thickness, as recorded in the Survey Memoir. As it has suffered erosion, it seems improbable that this was its original maximum; I have traced it up to about 30 feet O.D. or rather more, but I have drawn it higher in the section, as I am fully assured that it must extend farther.

A marine horizon occurs in the Pleistocene deposits which underlie the salting areas, as at Lion Point (west of Clacton), Stone Point (Walton), and Mill Bay (Dovercourt). It is characterized by an abundance of oysters, etc., and it is covered by a stony loam which appears to represent the Trail; while remains of *Elephas*, *Rhinoceros*, etc., may sometimes be found beneath it. At Lion Point[2] this horizon yields a great abundance of rolled and derived examples of *Unio littoralis* indicating the contemporary erosion of deposits of that character. The identification of this marine horizon, at and about the level of 5 feet below O.D., with the estuarine series at 20 to 30 feet above O.D. seems obvious, and is probably correct.

The scheme of correlation with other localities which has been already indicated suggests a Mousterian date for this period of submergence.

I have washed out samples of the hard clay (bed *k*), but without obtaining any useful result. Towards the western part of the

[1] Proc. Prehist. Soc. E. Anglia, vol. i (1912) p. 158.

[2] The series of deposits exposed on the foreshore here between tide-marks is as follows, from above downwards:—(1) Recent *Scrobicularia* clay; (2) Peat; (3) 'Lyonesse' surface, with Early Bronze-Age remains; (4) Brick-earth; (5) Marine horizon, yielding oysters and derived *Unio littoralis*; (6) Calcareous flinty gravel, containing Mesvinian implements and bones of *Elephas*, etc.; (7) London Clay.

Clacton channel I once found a thin line (scarcely more than a parting) of vegetable débris and shells in this hard clay, at a level of about 17 feet O.D. Neither shells nor plants gave any indication of estuarine influence, and the lists may be found in the columns marked *l*, in the accompanying Appendices. Bones of *Elephas*, etc. have also been found in the cliffs above the beach.

On one or two occasions I have seen temporary sections behind the sea-wall, and these have shown horizontally stratified sandy beds, with *Unio littoralis* and other non-marine mollusca in great abundance (these sites are marked *n* in fig. 1, p. 610).

Unio littoralis occurs in great profusion in all the lower beds, particularly *y*. After a heavy sea, I have frequently seen the present beach strewn over with this shell. It is found, not only in the position of life, but it frequently has the hinge-ligament well preserved.

Bed *y* seems to be generally the richest in remains of mammalia, and also in worked flints; but much of the collections has been obtained from specimens washed out by the sea, and found upon the shore. Many of the latter have peat-stained flints characteristic of bed *y* cemented on to them, with hard calcareous incrustations. These various remains are, however, by no means confined to bed *y*, and I have found many specimens in place in the upper beds as well, notably *x* and *w*.

The wooden spear[1] was dug out of bed *x*; it lay almost horizontally, but with the thicker and heavier end slightly depressed.

As may be noted from the plan of the beach (fig. 2, p. 610), the deeper part of the channel is filled by a thickening of bed *y*, while bed *x* is practically horizontal, and lies at about half-tide level, or slightly higher.

The 'nut-bed' looked very attractive, from the botanical point of view. It was about an inch thick, intercalated in bed *x*, and consisted of rolled pebbles of wood, hazel-nuts, and other woodland débris, mixed with a little white sand.

The Flint Industry.

The elephant-bed of Clacton yields abundant relics of the somewhat rare Mesvinian industry. It occurs equally in the foreshore deposit of the salting area at Lion Point, in company with *Unio littoralis* and the large mammalia. Apart from the simple flakes with very strong conical bulbs of percussion, and the trimmed flakes, a rude side-chopper having a zigzag segmental edge and a thick back is almost the only implement found.

This industry is described elsewhere,[2] but one point should be noted: namely, the frequency with which fresh Chalk flint and green-coated Bullhead flint were employed. These materials are not within reasonable access at the present day.

[1] O. G. S. Crawford, 'Man & His Past,' 1921; S. H. Warren, Q. J. G. S. vol. lxvii (1911) p. xcix.

[2] S. H. Warren, Proc. Prehist. E. Anglia, vol. iii (1922) p. 597.

The underground surface of the Chalk is about −200 feet O.D. at Clacton, but it soon rises to −150 to the north-east; while a well at Harwich proved the Chalk at about −55 O.D. The higher elevation of the land, coupled with a deeply trenched valley, of which the evidence has already been noted, would bring the Bullhead and Chalk flints within easy walking distance of the site.

The basement-bed limestone of the London Clay is also found at the bottom of the old river-channel, and I noted one block which measured roughly $9 \times 7 \times 5$ inches. Unless obtained from the erosion of Boulder Clay, this must also have been carried uphill by some means.

With regard to the dating of the Mesvinian industry, Continental research suggests that it is approximately contemporary with the Acheulian, although there is no typological or cultural association between the two; they are totally unlike in technique. On the other hand, the Mesvinian series, as so well represented at Clacton, exactly fills the place of what one would imagine the precursor of the Mousterian industry ought to be. If this be so: that is to say, if the Mesvinian be in fact (what it appears to be) a ruder and more primitive ancestor of the Mousterian industry, we are led to a very interesting result. Because, of the two industries (the Mesvinian and the Mousterian), the Mesvinian is the farther removed in typology from both the Acheulian and the Late Chellean, with which it is in part at least contemporary in time.

This evidence confirms a suggestion which has previously been made on the grounds of race-type: namely, that the Mousterian is a development of independent evolution and origin, and is not on the Chelleo-Acheulian line.

The proto-Mousterian tortoise-core industry, which is sometimes considered to be of Upper Acheulian date, is also intermediate in technique between the Mesvinian and the Mousterian proper. Thus, the flint industry points to a pre-Upper Acheulian date for the Clacton bed.

The Mammalia.

There is a marked difference in the frequency of different bones of the same animal. The antlers of *Cervus browni* occur in the greatest profusion; but, even after allowing for the fact that many of them are shed antlers, the jaw-bones are disproportionately scarce. Dense bones like the astragalus and calcaneum of *Bos primigenius* are also among the commonest fossils to be found, while both jaw-bones and horn-cores of the same species are about equally less common.

My own collection of *Elephas* remains includes a mandible in good preservation with four molars (the ante-penultimate and penultimate) in place, another mandible with the two last molars in place, and fifteen detached molars. There are also two portions of tusks, which are sufficiently long to show that they do not possess the curvature of *E. primigenius*. The J. Brown Collection

in the British Museum (Natural History), the private collection of Mr. H. Picton, and many specimens scattered in other museums, have been consulted, but no example of *Elephas primigenius* has been observed.

The great majority of the molars of the Clacton elephant are typical of *E. antiquus*, and although a few of them vary in the direction of *E. trogontherii*, it is usually only in some one character that they show this tendency, but not in the associated group of characters. It is generally the less worn teeth that look the least typical of *E. antiquus*, because I have noticed that the plates of enamel tend to be drawn nearer together towards the top of the tooth.

The bones of the limbs, ribs, vertebræ, etc., are very massive, and almost rival those of *E. meridionalis* in size, but there are no molars referable to this species.

The bovine remains in my possession include a fine pair of horn-cores of large size referable to *Bos primigenius*, and a large collection of limb-bones of massive proportions. There are also lighter limb-bones which probably belong to Bison.

There is one bone, a metacarpus, representing a small bovine, smaller than the ordinary *Bos longifrons*, and probably belonging to the same species as the metatarsus found by Mr. A. Wrigley at Temple Mills. I think that it must be the species described by Owen under the name of *Bison minor*; very little, however, is known about it. This metacarpus is damaged, but its approximate dimensions are:—length=155 or 160 mm.; width of proximal end =48·5 mm.; circumference=84·5 mm. I am indebted to Dr. C. W. Andrews for having carefully compared this bone, in common with many other critical specimens, at the British Museum (Natural History).

Of the cervine antlers, those belonging to *Cervus browni*[1] are by far the most abundant; but they are usually much damaged. The best-preserved antler in my collection is referable to *C. elaphus*. There are also quite a number of broken fragments of the antlers of a big cervine, probably *C. megaceros* (or perhaps *Alces machlis*), or possibly even both may be present. There is a well-preserved lower jaw which presents certain peculiarities, particularly in the unusual development of the accessory column of the last molar. If it be characteristic of *C. browni*, it would be well worth figuring and describing in detail; but, in the absence of comparative material, it appears to be impossible to be sure of this.

The cervine limb-bones fall into three corresponding groups: namely, those of the big deer, an intermediate group which agrees with *C. elaphus*, and a group of smaller bones which may (I think) be correlated with the *C. browni* antlers without risk of mistake. The bones of *C. browni* are considerably smaller than those of *C. elaphus*, but larger than the living *C. dama*; to the

[1] W. B. Dawkins, Q. J. G. S. vol. xxiv (1868) p. 511.

Comparative Measurements in Millimetres of Cervine Bones.

	Cervus browni.					*Cervus dama.*				*Cervus elaphus* (Caucasus).			
	Long.	Prox.	Dist.	Circ.		Long.	Prox.	Dist.	Circ.	Long.	Prox.	Dist.	Circ.
Humerus ...	...	...	48	...	l	191	48·7	37·1	67·2	298	87·7	68·4	120
	...	...	40·5	...	s								
Radius	250	48·5	41	80	l	201·5	37·4	34·7	59	318	62·9	61	±100
	223	41	±37	64	s								
Metacarpus ...	±234	33·5	±31	67·5	l	188·5	28·7	28·1	53	271·5	47·8	47·6	90
	230	30	±28	64									
	218	31·9	±29·2	62·5	s								
Tibia	...	...	39	75		270	33·5	53·3	69	399	84·8	55·5	101
Metatarsus ...	260	31	36·4	77	l	218·8	25·8	29·4	56	313	42·5	47·8	93·5
	245	29	33·7	67	s								
Calcaneum......	102·5 × 36·5 × 29					81·6 × 27·9 × 20·5				126 × 44 × 36·5			
Astragalus......	49 × 30 × 25					35·1 × 23·9 × 19·8				62 × 37·7 × 32·8			

The letters *l* and *s* indicate the largest and the smallest examples referred to *C. browni*.

eye they look more slender in their proportions than those of *Cervus elaphus*; but the difference in the length-circumference index is not so great as one would expect. Two metatarsi of *C. browni* give indices of 27·4 and 29·6, as compared with two of *C. elaphus* which give indices of 29·9 and 30·3.

The bones of *C. elaphus* from Clacton are, for the greater part, smaller than those of a recent skeleton from the Caucasus, in the British Museum (Natural History), marked 689 *x*, of which measurements are given in the accompanying table (p. 616). The chief difference is in the width, which is often 15, or even 20, per cent. less in the case of the Clacton bones; the difference in length is less considerable. The measurements of a *C. dama*, also in the British Museum (Natural History), are likewise tabulated for comparison with the bones of *C. browni*.

The *Rhinoceros* remains fall into two groups, massive and slender; and, after careful comparison of the upper molars at the Natural History Museum, Dr. C. W. Andrews and Mr. Martin Hinton came to the conclusion that two species were represented here: namely, *Rh. megarhinus* de Christol (=*Rh. leptorhinus* Cuvier); and *Rh. hemitœchus* Falconer (=*Rh. leptorhinus* Owen). Some French and other authorities, however, consider that these two are one species, for which they use the name of *Rh. merckii*. Although the two species are very closely related, there do seem to be differences of character, particularly in the upper molars, associated with differences of size, the *Rh. megarhinus* being the massive form and the *Rh. hemitœchus* the slender. It seems to me probable that we may be dealing with an evolutionary change.

It might be urged that the differences between *Rh. megarhinus* and *Rh. hemitœchus* might well be those of sex in the same species; but, as Mr. Hinton points out, their time-range is not the same, the former appearing earlier (in the Forest Bed), and also disappearing earlier, than the latter.

The comparative weight of the limb-bones is well illustrated by the radius, the massive Rhinoceratan radius having a circumference of 160 mm., while two examples of the slender form measure 126 mm. each. Five specimens of the radius in my collection from the Lea-Valley Arctic deposits, where *Rhinoceros antiquitatis* alone is represented, give corresponding measurements of 186, 166, 161, 160, and 154 mm. respectively. The depth, from above downwards, of the symphysis of the lower jaw of the two Clacton forms is 58 and 35·5 mm. respectively.

Attention has been drawn to differences in the enamel of the molars of *Rh. megarhinus* and *Rh. hemitœchus*. Dr. Andrews doubts whether much reliance can be placed upon this, and it is certainly very difficult to find any difference in the lower molars, assuming that the difference in size also represents the specific difference. But, in my specimens of the upper molars, there certainly is a difference, although it may be no more than accidental. In *Rh. hemitœchus* the enamel appears to the eye more

minutely granular, and, under a lens, is seen to be covered by minute, but sharply defined, vertical ribbings, with granules at intervals. In the more massive species the surface of the enamel is generally smoother, and the ribbings broader but less sharply defined.

Other remains.—I have obtained several teeth of the pike and numerous minor remains, such as some scales of a perch-like fish, and a fragment of the carapace of a crustacean (probably crayfish).

CLACTON MAMMALIA.

R=rare; C=common.	Owen, 1846.	Dawkins, 1869.	Survey, 1880.	1923.
Arvicola amphibia Desm.	...	...	+	
Bos bison	?	+	+	?
Bos (*minor* Owen) ?	...	...	...	v.R.
Bos primigenius Bojan.	+	+	+	v.C.
Capra sp.	+	...	...	R.
Castor sp.	+	...	...	v.R.
Cervus dama Linn.	...	...	*	
Cervus browni Dawkins	...	+	+	v.C.
Cervus elaphus Linn.	+	+	+	C.
Cervus giganteus (=*Megaceros*)	?	+	+	?
Elephas antiquus Falconer	...	+	+	v.C.
Equus caballus Linn.	+	+	+	R.
Felis leo var. *spelæa* Gold.	+	+	+	
Hippopotamus	...	...	*	
Hyæna spelæa Gold.	...	...	*	
Microtus agrestoides Hinton ?	...	...	...	v.R.
Rhinoceros megarhinus de Christ. }	+	+	+	C.
Rhinoceros hemitæchus Falconer }				C.
Ursus sp.	+	...	+	

Conclusion.

If we sum up the evidences of dating, the stratigraphy points to some part of the 50-foot, or Taplow, Terrace stage, apparently not the earliest, and certainly not the latest, part of that stage. The cutting of the deep channel shows that it was later than the period of rejuvenation; while the silting-up may (but not necessarily must) have been associated with the first arrest of erosion, which subsequently culminated in submergence up to at least 30 feet O.D., or more. The mammalia might be either Chellean or Early Acheulian, but could not be regarded as Late Acheulian. The mollusca indicate a narrower correlation: namely, later than the *Hippopotamus* beds of Little Thurrock, and earlier than the brick-earths of Crayford with their 'mixed' fauna and their Mousterian, or more probably Early Mousterian, industry. The plants indicate

approximate contemporaneity with West Wittering and Selsey, which had the same physical history as Clacton itself. The Mesvinian flint-industry points to some part of the Acheulian stage, probably the earlier part. Thus the various lines of independent evidence are supplementary one to the other, and there is no undue difficulty that needs to be explained away.

Finally, it only remains for me to pay the warmest tribute to the numerous collaborators in both the Clacton and the Lea Valley work; particularly to the late Mr. Clement Reid, Mrs. E. M. Reid, Miss M. E. J. Chandler, Mr. A. S. Kennard, Mr. B. B. Woodward, Mr. E. T. Newton, Dr. A. Smith Woodward, Dr. C. W. Andrews, Mr. Martin Hinton, Mr. T. H. Withers, and Mr. James Groves.

APPENDIX I.—*The* FOSSIL FLORA *of* CLACTON-ON-SEA. By Mrs. ELEANOR MARY REID, B.Sc., F.L.S., F.G.S., and Miss MARJORIE ELIZABETH JANE CHANDLER.

The investigation of the fossil flora of Clacton was first begun by the late Clement Reid in 1916, from material collected by Mr. S. Hazzledine Warren. The work was never completed, and, at the further request of Mr. Warren, it was taken up again in the spring of 1922 by ourselves, when we re-examined the whole material. By far the greater number of Mr. Reid's 111 determinations remain unaltered; but, in the case of a few, we consider that he was mistaken, and further research has revealed a considerable number of unrecognized, or undetermined, species, bringing the total up to 135, a list of which is appended (facing p. 622).

Before making any comments of our own, the conclusions to which Mr. Reid's work had led him must be stated. These may be gathered from his letters to Mr. Warren as the work progressed, between February 4th and April 5th, 1916. A few extracts from these follow here.

'March 2, 1916 . . . The flora is most interesting, and is well worth further work, as it ought to throw much light on climatic conditions. Have you been able to make out where the stream came from, and what were the deposits that lined its banks? The flora does not agree with that of a stream flowing through London Clay; it points either to a dry climate or to dry gravelly stream-banks: I cannot say which.'

'March 16, 1916 . . . These 58 species point clearly to a small stream (not estuarine), bordered by sandy bluffs; and I do not at present think that the stream came from a Chalk area. The climate was probably somewhat drier and warmer than now—in fact the evidence agrees with West Wittering and Selsey; but the drought and warmth may have been only in the summer.'

'March 21, 1916 . . . I have now worked through all the material critically, and have determined about 110 flowering plants, three or four others

are quite determinable, if I can lay my hands on living representatives; the rest are poorly preserved, but may amount to another eight or ten .... the deposit is well worth further search. Its dry-soil character is remarkable .... The general character of the flora agrees in a striking way with that of West Wittering, though many of the species are different, and the southern forms found at the two localities are not the same.'

'March 29, 1916 ... In the first place, I want to draw your attention to the very large proportion of the plants represented by one or two specimens only. This shows that there must have been many more species, and that we have nothing like exhausted the local flora .... I see no sign of a climatic change [in the different beds], and the flora seems practically the same from top to bottom ... The general character of the flora is so unusual that my comments will need a good deal of consideration, and I hope to be able to run down two or three more species which are probably no longer living in Britain.'

The letters from which these extracts are taken were received from Mr. Hazzledine Warren in October this year (1922), after we had completed our re-examination of the fossils, and had formed an independent opinion as to the significance of the flora. In essentials, that opinion is entirely in agreement with that of Mr. Reid. On the minor points, such as the character of the stream, it is unnecessary to add anything to the quotations that have been given, as Mr. Reid was better qualified to judge of such matters than we are.

The character of the flora as a whole leaves no doubt that it flourished under temperate conditions, and the great prevalence of dry-soil species shows that the ground must have been dry, and possibly waste in the sense of being sparsely inhabited. Whether this dryness was merely local, can hardly be answered by considering this one flora; but evidence which we will presently adduce has led us to the conclusion reached by Mr. Reid, that the Clacton flora was approximately contemporaneous with that of West Wittering and Selsey, both of which indicate dry conditions. If this be so, it is legitimate to infer that the dryness was not merely local, but climatic.

We will now pass on to examine in detail the botanical evidence for assigning the Clacton deposits to the Interglacial period of West Wittering and Selsey, rather than to the pre-Glacial period of the Cromer Forest-Bed.

An analysis of the three floras shows that (leaving out of account seashore plants) when land-plants as opposed to marsh- and water-plants, are considered, Clacton has 41 per cent of dry-soil species, West Wittering and Selsey together 40 per cent., and the Cromerian 31 per cent.

Again, if comparison of actual species be made, West Wittering and Selsey show 60 per cent. of species in common with Clacton, as against 51 per cent for the Cromerian, although the Cromer localities are so much nearer to Clacton, and similarly situated, and would therefore be more likely to have had similar floras, if

they had been contemporaneous. Not only so, but, if peculiar individual species be considered (leaving out of account *Najas minor*, which is common to the three floras), all the exotic Cromerian species, except *Picea excelsa*, and the rare living species, such as *Najas marina* and *Stratiotes aloides*, are absent from Clacton; whereas the few West Wittering and Selsey rarities (except *Najas graminea*) are found. The Clacton *Cratægus*, though not identical with the West Wittering species, is nearer to it than to any other, either fossil or living.

It is upon this evidence that we have independently reached the same conclusion as Mr. Reid: namely, that the Clacton deposit was probably contemporaneous with those of West Wittering and Selsey.

We add the description of two fossil species of *Cratægus*, the one from Clacton, and the other from West Wittering, both apparently allied to *C. pyracantha*. The West Wittering species, although it was discovered many years ago by Mr. Reid, and may have been referred to *C. pyracantha*, is distinct from that species. We have, therefore, taken this opportunity of describing and naming it.

CRATÆGUS CLACTONENSIS sp. nov. (cf. *C. pyracantha* Medic.).

Diameter of berry = 3 mm.; diameter of carpels = 2·5 mm.

Carpel obovate-cuneate, narrow, broadest at two-fifths of the distance from the apex. Ventral margin straight; dorsal surface uniformly convex, contracted or depressed over the nude area; junction of adherent and nude areas about three-quarters of the distance from the apex on the ventral margin, and about a quarter of the distance from the apex on the dorsal face; style small, terminal, patent, very slightly sunk below the convex top of the carpel; surface finely granulate.

Length of carpel = 2·25 mm.; breadth = 1·25 mm.

One perfect berry was found.

Fig. 1.—Cratægus clactonensis *sp. nov.* *(Length = 2·25 mm.; breadth = 1·25 mm.)*

The species is almost certainly extinct.

Locality.—Clacton-on-Sea (Essex).

Cratægus reidii sp. nov. (cf. *C. pyracantha* Medic.).

Carpels 5 in the berry, lunate, broadest at or near the middle. Ventral margin straight, occasionally facetted below; dorsal surface convex and markedly contracted over the nude area; junction of the two areas four-fifths of the distance from the apex on the ventral margin and one-third of the distance from the apex on the dorsal face; style large, patent, somewhat sunk below the sub-gibbous top of the carpel; surface finely granulate.

Fig. 2.—Cratægus reidii *sp. nov. West Wittering. (Length =3 mm.; breadth=1·75 mm.)*

Length=from 4·25 to 2 mm.; breadth = from 2·25 to 1·0 mm. Many carpels have been found which vary greatly in size, but otherwise agree in their characters. The average length is 3 mm. and the breadth 1·75 mm.

The species is almost certainly extinct. It is named after Mr. Clement Reid, who first found and determined it as a *Cratægus*.

Locality.—West Wittering.

For comparison with the above, we give the description of the living *C. pyracantha* Medic.

Cratægus pyracantha Medic.

Carpels 5 in the berry; average diameter of united carpels = 4 mm. Carpels gibbous, broadest below the middle; ventral margin straight and facetted at the base; dorsal surface very convex, contracted over the nude area; junction of the two areas four-fifths of the distance from the apex on the ventral margin and half the distance from the apex on the dorsal face, the nude area being markedly depressed; style large, patent, completely sunk below the gibbous apex.

Fig. 3.—Cratægus pyracantha, *recent. (Length=3 mm.; breadth=2 mm.)*

Average length = 2·75 mm.; average breadth = 2 mm.

The occurrence of these two species of *Cratægus* at Clacton and West Wittering respectively is of very great interest.

Clacton Temperate Flora

Northern-most		o = land-plants, as distinct from marsh or water-plants. ✠ = not British	Mixed	L	Q	R	W	Nut	X	Y	[illegible]	Z				
	1.	*Clematis vitalba* Linn.	×							×						
	2.	*Thalictrum flavum* Linn.	×							×	×					P
	3.	*Ranunculus acris* Linn.	×							×	×					
	4.	— *aquatilis* Linn.								×	×					P
	5.	— *bulbosus* Linn.								×	×					
	6.	— *Flammula* Linn.								×						P
	7.	— *parviflorus* Linn.						×	×	×	×					
	8.	— *repens* Linn.	×			×	×			×	×					P
	9.	— *sceleratus* Linn.		×						×						
	10.	*Nuphar luteum* Linn.						×								
	o 11.	*Fumaria* sp. (?)								×						
	12.	*Barbarea vulgaris* R. Br.								×						
	o 13.	*Cardamine impatiens* Linn.								×						
	o 14.	*Brassica nigra* Linn.														
	o 15.	*Viola hirta* Linn.	×			×		×		×						
	o 16.	— *odorata* Linn. ?								×						
	o 17.	— *sylvestris* Reich.					×	×				×				
	o 18.	— *tricolor* Linn.							×					×		
	o 19.	*Lychnis diurna* Sibth.								×						
	20.	*Malachium aquaticum* Fr.						×	×							
	o 21.	*Stellaria Boraeana* Jord.								×						
	22.	— *Holostea* Linn.													I	P
	23.	— *palustris* Retz.														
	24.	*Arenaria trinervia* Linn.	×													
	25.	*Montia fontana* Linn.								×						
	26.	*Hypericum perforatum* Linn.								×						
	27.	*Ilex Aquifolium* Linn.	×			×	×	×								
	28.	*Acer* (?). Specimens bad								×						
	29.	*Melilotus* (?). Do. do.								×						
	30.	*Vicia* (?). Do. do.								×						
	31.	*Prunus spinosa* Linn.	×							×	×					
	32.	*Rubus fruticosus* Linn.	×							×					I	P
	33.	*Potentilla Anserina* Linn.	×							×						
	34.	— *reptans* Linn.	×							×	×					
	35.	— *erecta* Hampe	×							×	×					
	36.	*Alchemilla arvensis* Lamk.								×						
	37.	*Agrimonia Eupatoria* Linn.	×							×	×					
	38.	*Rosa spinosissima* Linn.									×				I	
	39.	*Crataegus monogyna* Jacq.				×	×	×	×	×	×				I	
	40.	*Crataegus clactonensis* sp. nov.		×						×						
	41.	*Hippuris vulgaris* Linn.													I	
	42.	*Myriophyllum spicatum* Linn.						×	×	×					I	
	43.	*Petroselinum segetum* Koch														
	44.	*Sium erectum* Huds.														
	45.	*Aethusa Cynapium* Linn.		×				×	×	×						P
	46.	*Silaus flavescens* Bernh.							×	×						
	47.	*Peucedanum sativum* Benth.						×	×	×						P
	48.	*Heracleum Sphondylium* Linn.								×				×	I	P
	49.	*Caucalis Anthriscus* Huds.						×								P
		Umbelliferae, genus (?)								×						
	50.	*Cornus sanguinea* Linn.	×	×		×		×		×	×					P
	51.	*Viburnum Lantana* Linn.				×										
	52.	— *Opulus* Linn.	×			×	×	×								P
	53.	*Sambucus nigra* Linn.	×			×	×	×		×						
	54.	*Valeriana dioica* Linn.								×						
	55.	*Valerianella carinata* Loisel.								×						
	56.	— cf. *dentata* Poll.														
	57.	— *olitoria* Mœnch								×						
	58.	*Scabiosa Columbaria* Linn.	×							×						
	59.	*Eupatorium cannabinum* Linn.								×						
	60.	*Arctium* sp.							×	×				×		
	61.	*Centaurea nigra* Linn.								×						
	62.	*Carduus lanceolatus* Hoffm.	×						×	×				×		
	63.	— *nutans* Linn.								×				×		
	64.	*Lapsana communis* Linn.	×						×	×				×		
	65.	*Picris hieracioides* Linn.	×							×						
	66.	*Sonchus arvensis* Linn.								×				×		
	67.	— *asper* Hoffm.	×							×				×		
	o 68.	*Armeria maritima* Willd.								×						
	o 69.	*Solanum Dulcamara* Linn.								×		×				P
	o 70.	[illegible]	×							×		×		×		
	71.	[illegible]								×						
	72.	[illegible]							×							
	73.	[illegible]		×												
	74.	[illegible]								×		×				
	o 75.	[illegible]										×				
58	o 76.	[illegible]								×		×	×			
58	o 77.	[illegible]								×						
	o 78.	[illegible]								×		×			I	
	79.	[illegible]								×		×			I	
	o 80.	[illegible]													I	
	o 81.	[illegible]								×						
	o 82.	[illegible]								×					I	
	o 83.	[illegible] *annuus* Linn.								×					I	
	o 85.	*Chenopodium album* Linn.								×						
	o 86.	— *botryoides* Sm.								×						
54	o 87.	[illegible]										×				
	o 88.	[illegible]						×		×		×			I	
54	o 89.	— [illegible] Linn.								×						
	o 90.	*Atriplex patula* Linn.								×	×	×			I	
	o 91.	*Rumex Acetosella* Li[illegible]								×	×				I	
	o 92.	[illegible]								×	×	×			I	
57	93.	[illegible]								×		×				
56	94.	[illegible]								×					I	
	o 95.	[illegible]								×					I	
	o 96.	[illegible]								×	×	×			I	
	o 97.	[illegible]								×	×	×				
	o 98.	[illegible]								×					I	
	[illegible]	[illegible]														

Explanation of Symbols

[illegible]

Several species of small five-stoned fruits have been found in the Pliocene deposits of Castle Eden, Reuver, and Pont-de-Gail, but they were not found in the Cromer Forest-Bed or at Tegelen. Negative evidence is proverbially inadequate proof, and it may be that this form of *Cratægus* will yet be found in the two last-named deposits, even though very great quantities of material from both have been examined. In any case, one would wish to know the course of history which brought about the return of these small five-stoned species to Britain during Interglacial times.

Appendix II.—*The* Charophyta *from* Clacton-on-Sea.

By James Groves, F.L.S.

The fruits vary considerably in size and shape, and represent in my opinion two, or possibly three, species.

(1) The type to which most of the specimens belong resembles the fruit of the existing British *Chara hispida*, which it may well be. The length of the oogonium appears to be about 800 μ, but none of the full-grown specimens is perfect at the apex; the breadth=about 550 to 600 μ. It is usually broadest about the middle, and tapers slightly towards the base. The spiral cells show some eleven or twelve convolutions.

(2) The single dark fruit is apparently a different species, about the length of the first, though narrower (500 μ), and broadest about the middle but sub-cylindrical; and the spiral cells show rather more convolutions. Another fruit, a lighter-coloured, imperfect specimen, may belong to the same species.

(3) A single light-coloured specimen seems different from both 1 and 2. About as narrow as 2, but less cylindrical, tapering conspicuously at each extremity; length = probably about 82·5 μ; breadth = about 500 μ. The spiral cells would probably show twelve or thirteen convolutions. This might well belong to the existing species *C. fragilis*.

The oospores seem, in all cases, to be well preserved.

The fragments of stem and branches belong pretty certainly to a *Chara* of the section Diplostephanæ Diplostichæ, which includes *C. hispida* and *C. vulgaris*; in thickness they agree more closely with the latter than with the former.

APPENDIX III.—NOTE *on a* MANDIBLE *of a* VERY YOUNG *ELEPHAS ANTIQUUS from* CLACTON-ON-SEA. By CHARLES WILLIAM ANDREWS, D.Sc., F.R.S., F.G.S.

Some time ago Mr. Hazzledine Warren sent to me for examination the anterior portion of the lower jaw of a very young elephant, collected with numerous other Proboscidean remains from Clacton-on-Sea. Unfortunately, the teeth are missing; but, since all the other elephant-remains from the same horizon in this locality are referable to *Elephas antiquus*, it may be regarded as almost certain that this mandible is that of a fœtal or newly-born member of the same species.

Only the anterior portion of the jaw is preserved, the symphysial region being in an excellent condition: posteriorly the bone is broken away on both sides, a little behind the level of the anterior wall of the alveolus for the penultimate milk-molar. The symphysis is remarkable for its strongly developed beak, the upper surface of which seems to have made a very obtuse angle with the line of the alveolar border of the jaw: but, since this is much broken, the exact relations are not clear. Laterally, the sides of the beak are considerably pinched in; ventrally, it passes by a concave curve into the rounded and thickened posterior portion of the symphysis, the posterior face of which forms a broad, nearly vertical, spout-like channel.

The outer face of the mandibular ramus is strongly convex from above downwards; its upper alveolar border is so much broken that the anterior of the two mental foramina has come to lie at the upper edge of the jaw, and at first sight resembles an alveolus for a milk-molar. Behind this opening the alveolar border widens out, and after an interval of about 18 mm. we find the nearly circular alveolus of the antepenultimate milk-molar (M.m.2). The root of this tooth was single, there being no indication of bifurcation at the end. H. Pohlig[1] has figured a specimen of this tooth in which, as in our example, the root is single and nearly circular in section; on the other hand, in a specimen figured by A. Leith Adams,[2] the root bifurcates below, and the upper portion is more or less oval in section and divided by vertical grooves into an anterior and posterior column. Behind the alveolus of the antepenultimate milk-molar, and separated from it by an interval of about 5 mm., is the anterior wall of the empty alveolus of the much larger penultimate milk-molar (M.m.3). Unfortunately, all behind this point is missing on both sides of the jaw.

The only specimen of the young mandible of *Elephas antiquus*

[1] 'Dentition & Kranologie des *Elephas antiquus* Falc.' Nova Acta Acad. Cæs. Leop. Car. vol. liii (1889) pl. ii, fig. 5.

[2] 'Monograph on the British Fossil Elephants' 1877–81, pl. i, fig. 2.

with which I have been able to make a direct comparison is an imperfect jaw of an older and considerably larger individual from Ilford. This specimen (B.M. 21310) has been figured and described by Leith Adams [1] and is noticed by H. Falconer.[2] The former author definitely determines it as being *Elephas antiquus*; while the latter expresses some uncertainty. Assuming that, as seems probable, Leith Adams is right in his determination, this specimen (apart from its considerably larger size) shows much similarity to that now described. Thus, there is a distinct beak-like rostrum which passes below into a rounded chin. The rostrum is, however, much smaller in proportion to the remainder of the jaw than in the specimen here described; and the anterior milk-molar was not only much larger, but possessed two distinct roots: in this jaw M.m.3 is present and already considerably worn. When the wear-surface is placed horizontally, the posterior border of the symphysis is nearly beneath the anterior root of M.m.3. Perhaps, in a still more advanced state of wear, the direction of the grinding surface would be somewhat different, so that, when placed in a horizontal position, the symphysis would appear to extend still farther back, as in an older and larger specimen figured by Pohlig (*op. cit.* pl. iii, fig. 1 & pl. ix, fig. 1), in which it is beneath the anterior half of M.m.3. In this specimen the rostrum is wanting; this may, however, be partly due to the incompleteness of the jaw. Judging from the lateral view (*op. cit.* pl. ix, fig. 1), not only has the rostrum, but also the rounded chin, undergone reduction. It seems possible that the specimen here described and those figured by Leith Adams and Pohlig respectively, form a series ranging from a very small, perhaps fœtal, individual to one in which M.m.3 is considerably worn. If this be so, it is interesting to note the gradual disappearance of the rostrum with advancing age, the loss of the distinct chin, and the carrying-backwards of the posterior border of the symphysis. The presence of a marked rostrum is a primitive character reminiscent of the longirostrine stage through which the ancestors of all Proboscidea must have passed, and is tending to disappear with advancing life. At the same time, it must be noted that in some adult mandibles of the Mammoth (*Elephas primigenius*) the rostrum is very well developed, so that the degree to which it persists is variable, as it very often is in the case of structures which are undergoing reduction.

Some dimensions of this specimen (in millimetres) are:—

Antero-posterior length in a straight line (so far as preserved) ...	105
Greatest width	128
Length of the symphysis........	62

[1] *Op. cit.* p. 14 & pl. v, fig. 2.
[2] 'Palæontological Memoirs' vol. ii (1868) p. 178.

Appendix IV.—Note *on the* Rodent-Remains *from* Clacton-on-Sea. By Martin Alister Campbell Hinton.

For the greater part these remains are fragmentary and indeterminable; but some of the teeth, including a right m.$\bar{1}$, and a fragment of a left m.$^{\bar{1}}$ and a left m.$\bar{2}$ from Bed *q*, together with portions of two lower incisors from Bed *z*, belong to a small vole. Of these specimens the right m.$\bar{1}$ is the most important. Possessing, as it does, five closed triangles in addition to the posterior and anterior loops, it is clearly referable to the genus *Microtus*; and in its small size, enamel structure, and form of the anterior loop, it agrees exactly with many of the teeth obtained by Mr. A. S. Kennard and myself long ago, from the brick-earth of Grays Thurrock. The species from Grays is clearly a member of the *M. agrestis* group, to which I have applied the name *M. agrestoides*; and I have little doubt that the Clacton vole is either identical with, or else very closely allied to, the Grays species.

Mr. Warren has called my attention to the fact that *Arvicola amphibius* has been recorded from Clacton. This apparently rests upon the authority of John Brown, of Stanway, who, in describing his figure [1] of a 'Section of a Freshwater Formation near Walton, on the Essex Coast,' says of Bed 5:—

'Peat with subordinate and interrupted beds of marine aud freshwater shells. Incisive tooth of water rat, figured in pl. xi, 2, *Reliqu. Diluv.*';

and on the following page he says, rather more explicitly,

'Incisor tooth of water-rat, figured in *Reliquiæ Diluvianæ* pl. xi, fig. 2.'

Buckland, however, states in the explanation of his pl. xi that 'the specimens from 1 to 29, inclusive, are all from Kirkdale'; and I think that John Brown meant only to indicate that he had identified the tooth found in his Bed 5, with the aid of Buckland's figure of a Kirkdale specimen. The present location of John Brown's specimen is unknown, and nothing can, of course, be based upon such a record. But remains of a water-vole, that is, a species of *Arvicola*, occur abundantly in the brick-earth at Grays; and consequently there is no inherent improbability in this early record.

Part of a right mandibular ramus of a young adult beaver has also been found by Mr. Warren. This has part of the incisor and the four cheek-teeth in place; and it is not apparently distinguishable from jaws of beaver (*Castor fiber*) from the Fens.

[1] Magazine of Natural History, n.s. vol. iv (1840) p. 199.

APPENDIX V.—OSTRACODA *from the* ELEPHAS-ANTIQUUS BED *at* CLACTON-ON-SEA. By THOMAS HENRY WITHERS, F.G.S.

The freshwater Ostracoda submitted to me by Mr. Hazzledine Warren from the *Elephas-antiquus* Bed at Clacton, and now presented by him to the Geological Department of the British Museum, number well over five hundred specimens. An examination of these shows that four species only are represented, and, although the shells are extremely fragile, quite a large number of specimens have the two valves attached. All four species are still found living in the ponds and rivers of Europe, and two species, *Erpetocypris reptans* and *Ilyocypris gibba*, are quite common forms, with a very wide European distribution: they, moreover, occur fossil in the Weybourn Crag and in numerous Pleistocene deposits (including Grays, Clacton, and Whittlesey), while *I. gibba* is recorded from the Middle Hamstead Beds (Oligocene) of the Isle of Wight. Of the two remaining species, *Scottia browniana* is known living only at Lake Fadd (Bute), and *Potamocypris trigonalis* is known from Pegwell Bay; but T. Rupert Jones was of the opinion that this latter form was probably derived from the River Stour, which empties itself into the bay.

The numbers of specimens representing each species are, approximately: *E. reptans*, 200; *I. gibba*, 100; *S. browniana*, 200; and *P. trigonalis*, 50.

ERPETOCYPRIS REPTANS (Baird).

1836. *Candona reptans* Baird, Hist. Berwicksh. Nat. Club, vol. i, p. 99 & pl. iii, fig. 11.
1857. *Candona reptans* Baird: T. R. Jones, Pal. Soc. 'Monogr. Tert. Entomostraca' p. 16 & pl. i, figs. 7 *a*–7 *e*.
1874. *Cypris reptans* (Baird): Brady, Crosskey, & Robertson, Pal. Soc. 'Monogr. Post-Tert. Entomostraca' p. 128 & pl. ii, figs. 31, 32.
1889. *Cypris reptans* (Baird): T. R. Jones, Pal. Soc. 'Monogr. Tert. Entomostraca' Suppl. p. 10.
1889. *Erpetocypris reptans* (Baird): Brady & Norman, Trans. Roy. Soc. Dublin, vol. iv, pp. 84. 247 & pl. xiii, fig. 27.
1900. *Cypris reptans* (Baird): G. W. Müller, 'Deutschlands Süsswasser-Ostracoden' p. 58 & pl. xiv, figs. 4, 6, 12, 13, 17.

Distribution.—Recent: Great Britain and Ireland, Norway, Sweden, Germany, Tyrol, Bohemia, Palermo, South-Western France, Transylvania.

Fossil. Pliocene: Weybourn Crag. Pleistocene: Cambridgeshire (Barnwell and Whittlesey); Essex (Clacton and Grays). Post-Tertiary: Berkshire (Newbury); Cambridgeshire Fens; Lincolnshire (Casewick railway-cutting); Yorkshire (Hornsea); Norfolk (Mundesley and Sidestrand): Hertfordshire (near Hitchin); Essex (Edwardstone).

ILYOCYPRIS GIBBA (Ramdohr).

1808. *Cypris gibba* Ramdohr, Magaz. Gesellsch. Naturf. Freunde zu Berlin, Jahrg. ii. p. 91 & pl. iii, figs. 13, 14, 17.
1857. *Cypris gibba* Ramdohr: T. R. Jones, Pal. Soc. 'Monogr. Tert. Entomostraca' p. 15 & pl. i, figs. 3 *a*–3 *f*; woodc. fig. 1 (p. 16).
1874. *Cypris gibba* Ramdohr: Brady, Crosskey, & Robertson, Pal. Soc. 'Monogr. Post-Tert. Entomostraca' p. 127 & pl. xv, figs. 5, 6.
1889. *Cypris gibba* Ramdohr: T. R. Jones, Pal. Soc. 'Monogr. Tert. Entomostraca' Suppl. p. 9.
1889. *Ilyocypris gibba* (Ramdohr): Brady & Norman, Trans. Roy. Soc. Dublin, vol. iv, pp. 107, 248 & pl. xxii, figs. 1–5.
1900. *Iliocypris gibba* (Ramdohr): G. W. Müller, 'Deutschlands Süsswasser-Ostracoden' p. 88 & pl. xix, figs. 7, 8, 10, 14–19; pl. xx, figs. 17, 18.

Distribution.—Recent: Great Britain, Sweden, Germany, Holland, Switzerland, Hungary, Russia, France.

Fossil. Oligocene: Middle Hamstead Beds, Isle of Wight. Pliocene: Weybourn Crag. Pleistocene: Cambridgeshire (Whittlesey); Kent (Reculvers); Essex (Clacton and Grays). Post-Tertiary: Scotland (Crofthead, Dipple, and Terally); Cambridgeshire Fens; Lincolnshire (Branston Fen); Yorkshire (Hornsea); Norfolk (Mundesley and Sidestrand); Dorset (Chesilton, Portland).

SCOTTIA BROWNIANA (Jones).

1857. *Cypris browniana* T. R. Jones, Pal. Soc. 'Monogr. Tert. Entomostraca' p. 13 & pl. i, figs. 1*a*–1*d*.
1889. *Cypris browniana* T. R. Jones, Pal. Soc. 'Monogr. Tert. Entomostraca' Suppl. p. 9.
1889. *Scottia browniana* (Jones): Brady & Norman, Trans. Roy. Soc. Dublin, vol. iv, p. 72 & pl. ix, figs. 23, 24; pl. xi, figs. 19–25.

Distribution.—Recent: Loch Fadd (Bute).

Fossil. Uppermost Pliocene: *Unio* Bed at Sidestrand (Norfolk); Pleistocene: Clacton (Essex).

POTAMOCYPRIS TRIGONALIS (Jones).

1857. *Cytherideis trigonalis* et var. *lævis*, T. R. Jones, Pal. Soc. 'Monogr. Tert. Entomostraca' p. 47 & pl. ii. figs. 2 *a*–2 *h*.
1889. *Potamocypris trigonalis* et var. *lævis*, T. R. Jones, Pal. Soc. 'Monogr. Tert. Entomostraca' Suppl. p. 11.

Distribution.—Recent: Pegwell Bay, Kent (probably washed in from the River Stour).

Fossil. Pliocene: Norwich Crag, Bramerton (Norfolk); Pleistocene: Clacton (Essex).

A smooth form of this species (var. *lævis*) was recorded by T. Rupert Jones from the Weybourn Crag of East Runton (Norfolk), and as occurring plentifully in the Pleistocene sand of Grays (Essex). Some of the specimens now described from Clacton are smoother than the others, but in other respects they agree with the typical form.

APPENDIX VI.—*The* NON-MARINE MOLLUSCA *of* CLACTON-ON-SEA. By ALFRED SANTER KENNARD, F.G.S., and BERNARD BARHAM WOODWARD, F.L.S., F.G.S.

An account of the non-marine mollusca of Clacton based on the known collections was published by us in 1897,[1] when we were able to record sixty-one species; but of these fifteen were unconfirmed records. Since then Dr. Frank Corner has kindly sent us a small series principally obtained from the estuarine bed, while the extensive collection of the late Dr. Henry Woodward has passed into our keeping. From this additional material we were able to raise the total number of known species to sixty-seven.

We are greatly indebted to Mr. S. Hazzledine Warren for placing at our disposal the results of his systematic exploration of these beds. The number of known species is now eighty-two, the longest list from any English Pleistocene deposit. One species, *Vertigo pusilla* Müller, although recorded by S. V. Wood,[2] we have omitted, since there are no examples extant. In the following table we have indicated in the first column the results of previous work, while the remainder show the frequency of each species in the various layers recognized by Mr. Warren.

TABLE OF DISTRIBUTION OF THE NON-MARINE MOLLUSCA.

[R=rare; C=common.]	Former Collections.	*l*	*q*	*r*	*w*	Nut-Bed.	*x*	*y*	*y**	*z*
Limax maximus Linn.	...	R	...	...	...	...	...	...	...	R
L. arborum Bouch.-Chant.	...	...	...	...	R	...	R	R		
Vitrea crystallina (Müller)	R	...	...	...	...	...	...	R	...	R
Helicella cellaria (Müller)	...	...	...	...	...	...	...	R		
H. nitidula (Draparnaud)	...	...	...	R	...	...	...	R		
H. radiatula (Alder)	R	R	R	R	...	...	R	R	...	R
Zonitoides nitidus (Müller)	R	...	...	R	R	...	C	R		
Z. excavatus (Alder)	R	...	R	R	...	...	...	R		
Petasina fulva (Müller)	R									
Arion sp.	R									
Punctum pygmæum (Draparnaud)	...	...	R	...	...	...	R	...	...	C
Goniodiscus rotundatus (Müller)	R	...	...	R	...	...	...	R		
G. ruderatus (Studer)	R	...	R	R	...	...	R	R	...	R
Jacosta itala (Linn.)	...	...	...	R	...	...	...	R		
J. crayfordensis (Kenn.&B.B. Woodw.)	R	R	R	C	...	...	...	R	R	R
Fruticicola hispida (Linn.)	C	R	C	C	R	...	C	C	R	C
Acanthinula aculeata (Müller)	R	...	...	...	...	...	...	R	...	R
Vallonia pulchella (Müller)	C	...	C	...	C	...	C	C	...	C
V. excentrica Sterki	C	R	R	R	C	...	R	C	R	R
V. costata (Müller)	C	...	C	R	C	...	C	C	...	C
Chilotrema lapicida (Linn.)	R	...	...	R						
Arianta arbustorum (Linn.)	R	...	R	...	...	...	...	...	...	R

1 'Essex Naturalist' vol. x, pp. 97–100.
2 'Monogr. Crag Moll.' vol. ii, Pal. Soc. 1856, pp. 307–10.

[R=rare; C=common.]	Former Collections.	*l*	*q*	*r*	*w*	Nut-Bed.	*x*	*y*	*y**	*z*
Helix nemoralis Linn.	C	R	R	R	...	...	R	R	...	R
H. hortensis Müller	R									
Ena montana (Draparnaud)	R	.	...	R						
Cochlicopa lubrica (Müller)	R	..	R	R	R	..	R	R	...	C
Azeca goodalli (Férussac)...............	R	...	...	R	...	...	.	R	..	R
Pupilla muscorum (Linn.)	R	...	R	R	C	...	R	...	...	C
Vertigo antivertigo (Draparnaud) ..	R	...	...	...	...	...	.	R	...	R
V. pygmæa (Draparnaud)	R	...	.	...	...	..	.	R		
V. moulinsiana (Dupuy)	R									
Columella edentula (Draparnaud) ...	R									
Truncatellina cylindrica (Férussac) .	...	...	...	...	R	...	...	...	...	R
Clausilia rugosa Draparnaud	R	R	...	...	R					
C. ventricosa Draparnaud	R	...	...	R	...	..	R	R	...	R
Succinea pfeifferi Rossmässler.........	C	..	R	R	C	...	R	R	...	R
Carychium minimum Müller......	R	...	R	...	R	..	R	R	...	C
Ancylus lacustris (Linn.)	R	R								
Ancylastrum fluviatilis (Müller)......	C	R	C	R	C	...	R	C	R	
Limnæa auricularia (Linn.)............	R	R	...	R	...	R	R	R	R	
L. pereger (Müller)	C	R	C	C	C	R	C	C	R	C
L. palustris (Müller).....................	R									
L. truncatula (Müller)	C	...	...	R	C	...	C	R	...	C
L. stagnalis (Linn.)	R	...	...	..	...	...	R		.	
Planorbis albus (Müller)	C	R	C	C	C	R	C	C	...	C
P. lævis Alder	R	...	.	R	...	...	...	R		
P. crista (Linn.)	R	R	C	R	C	...	C	C	...	C
P. carinatus (Müller).....................	C	R	...	R	C	...	R	C	R	
P. planorbis (Linn.)	R	..	R							
P. vortex (Linn.)	...		...	...	...	...	...	...	...	R
P. leucostoma Millet	R	...	R	R						
P. contortus (Linn.)	R	...	R	R	...	...	R	...	...	R
P. complanatus (Linn.)..................	R	...	..	...	R	...	R	R	...	R
Segmentina nitida (Müller)	R	...	...	...	...	...	R			
Physa fontinalis (Linn.)	...	.	...	R	...	...	...	..	...	R
Aplexa hypnorum (Linn.)............. .	...	...	...	...	...	...	...	R		
Belgrandia marginata (Michaud) ...	C	C	R	R						
Paladhilia radigueli (Bourguignat)..	C	R								
P. deani (Kendall)	R									
Pseudamnicola confusa (Frauenfeld).	R									
Bithynia tentaculata (Linn.)	C	C	C	C	C	C	C	C	R	C
B. leachi (Sheppard)	...	...	...	...	R	...	R	C	...	R
Vivipara diluviana (Kunth)	R									
Valvata piscinalis (Müller)	C	C	C	C	C	R	C	C	...	C
V. antiqua Sowerby	...	C								
V. cristata Müller	R	R	R	R	R	...	R	C	...	C
Unio tumidus Retzius	...	R								
U. littoralis Lamarck	C	R	C	C	C	C	C	C		
Anodonta anatina (Linn.)...............	R	...	..	...	...	...	...	R		
Corbicula fluminalis (Müller)	R									
Sphærium corneum (Linn.)	C	C	C	C	C	R	C	C	...	R
Pisidium amnicum (Müller)	C	C	C	C	C	R	C	C	R	C
P. astartoides Sandberger.......	C	C	R	C	R	...	R	R	...	R
P. cinereum Alder	C	...	C	...	...	...	C	C	R	C
P. nitidum Jenyns	C	R	R	R	...	...	C	R	R	C
P. personatum Malm	R									
P. pusillulum B. B. Woodw.	C	...	C	C	R	...	C	R	R	R
P. milium Held	R	..	R	R	...	...	R	R		.
P. subtruncatum Malm..................	C	...	C	R	C	...	C	C	...	C
P. henslowanum (Sheppard)............	C	C	C	C	C	R	C	C	C	C
P. supinum A. Schmidt..................	R	R	...	R						
P. obtusalastrum B. B. Woodw.	...	...	...	...	...	...	R			
Totals. . . 82	68	28	36	44	30	9	41	49	13	41

From the estuarine bed three species were obtained, namely :—

Paladilhia radigueli (Bourguignat) common,
Vivipara diluviana (Kunth) rare,
Corbicula fluminalis (Müller) rare,

as well as two marine species, namely :—

Scrobicularia plana (Da Costa).
Cardium edule Linn.

Thus sixteen new records are added to the list. while eight known species were not represented in Mr. Warren's collection.

Notes on the Species.

LIMAX.—Hitherto no species of *Limax* has been recorded from Clacton. Why this genus should be so rare in this deposit is puzzling, for, as a rule, it is quite common in Pleistocene beds.

ZONITOIDES EXCAVATUS (Alder).

An extremely rare form in the Pleistocene, Dog Holes, Warton (Lancashire), is the only other record. It is unknown living in Essex, though it is known from the early Holocene of Copford and Chignal St. James.

FRUTICICOLA HISPIDA (Linn.).

This species is represented by the large flat form, so common at Woodston (Huntingdonshire), to the total exclusion of the high-spired *liberta* (Westerlund). It is, however, possible that the *Helix conoidea* Sowerby [1] may be *liberta*, although we have seen nothing from Clacton that in any way resembles Sowerby's species. In the collection of Dr. Henry Woodward were several examples of a high-spired *hispida* labelled 'Clacton', which came from the same source as the shells described by G. B. Sowerby: namely, John Brown, of Stanway.

The locality ascribed to Dr. Woodward's examples is certainly incorrect, for they are manifestly from Grays. Is it possible that a similar mistake was made in the specimens described by G. B. Sowerby?

In the early days of Geology the importance of recording the exact locality of specimens was too often not recognized, while the rivalry of collectors was frequently the cause of wrong localities being attached to specimens.

ENA MONTANA (Draparnaud).

The southernmost record for this species in the Pleistocene; Woodston, Orton Waterville, and the Cambridge gravels being the only other localities.

[1] Ann. Nat. Hist. vol. vii (1841) p. 429.

Clausilia ventricosa Draparnaud.

Originally recorded from the Pleistocene of Woodston,[1] it has since been recognized from Orton Waterville and Apethorpe. Probably the early records of *Clausilia biplicata* (Montagu) from Grays also really refer to this species.

Limnæa auricularia (Linn.).

The small inflated form so characteristic of the Pleistocene deposits alone occurred. This is quite unknown living in England, although we have seen examples from Germany as var. *monnardi* Hartmann.

Limnæa truncatula (Müller).

As in all Pleistocene beds, the examples of this species are small; the large form so common in the Holocene and living is quite unknown in the Pleistocene.

Paladilhia radigueli (Bourguignat).

This species occurred only, and that but rarely, in Bed *l*, though it was common in the Estuarine Bed. From this one might infer that it was a brackish-water form, yet it occurred commonly in the freshwater deposit of Grays, and rarely at Swanscomb, Crayford, and Ilford. The closely-allied form, *P. deani* Kendall, hitherto only known from Woodston and Orton Waterville also occurred, but its exact horizon is unknown.

Pseudamnicola confusa (Frauenfeld).

Hitherto unrecorded from Clacton, it is a rare species in the Pleistocene: Stutton, West Wittering, and Stone being the only other localities.

Bithynia tentaculata (Linn.).

The most abundant species in these beds, but none of the examples attain the size of recent and Holocene examples.

Vivipara diluviana (Kunth).

Clacton and Swanscomb are the only English localities for this interesting species, which is said to be still living in the South of Russia. This is the *Paludina clactonensis* S. V. Wood.[2] Though it was found by Mr. Warren only in the Estuarine Bed, we have seen examples which from their condition probably came from Bed *l*. Judging from the preservation of all the examples, there is a strong probability that they are derivatives from a yet older bed.

[1] Journ. of Conch. vol. xiv (1913) pp. 83 & 89.

[2] 'Monograph of the Crag Mollusca' 2nd Suppl. p. 69 & pl. i, figs. 4 *a* & 4 *b*.

Valvata antiqua Sowerby.

This species occurred, not uncommonly, only in Bed *l*, and, if we judge from their condition, the specimens found are certainly derivatives. This is an early Pleistocene form known only from Grays, Kelvedon, Hoxne, and Swanscomb. It has hitherto never occurred with *Valvata piscinalis* (Müller), and in this case the two species are assuredly not contemporary.

Unio littoralis Lamarck.

This form attains its maximum of size in these beds, one pair in the British Museum (Natural History) measuring $69 \times 47 \times 28$ mm. Crayford examples come next in size, while the shells from Barnwell, Swanscomb, and Peterborough are much smaller. This is merely the result of environment, for the species prefers mud to gravel.

Corbicula fluminalis (Müller).

Decidedly rare at Clacton, and apparently occurring only in the Estuarine Bed. There again the condition of the specimens leads one to infer that they are derivatives.

Anodonta anatina (Linn.).

A rare Pleistocene fossil, the only other locality for it being Grays.

Conclusions.

Though we have always borne in mind the probability that a river-deposit might contain derivatives, and thus lead to confusion, this is the first instance in which we can say definitely that this is exactly what has occurred. Besides the three species that we have already claimed as derivatives (*Valvata antiqua*, *Vivipara diluviana*, and *Corbicula fluminalis*) there are examples of *Limnæa pereger* and *Bithynia tentaculata* which we would place in the same category; but, since there are abundant contemporary examples of these two species, no confusion is likely to arise. In all probability, these derived specimens have been washed out of an early Pleistocene deposit of the same age as Swanscomb: that is, High Terrace of the Thames. As further evidence in support of our view, we may mention that Bed *y* yielded rolled examples of two marine species, *Purpura lapillus* (Linn.) and *Nucula* sp., as well as three indeterminable examples which are probably of Eocene age.

These beds are clearly of one age, and no great interval of time separates the highest from the lowest. In our opinion they belong to the same Pleistocene stage as the Woodston, Orton Waterville, Barnwell Abbey, Grantchester, Ilford (Uphall), West Wittering, and Stutton deposits. In several of these there can be read the same physical history.

The gradual elevation of the land which had been proceeding, doubtless intermittently, since early Pleistocene times received a temporary check, and a slight reverse movement set in, thus enabling the sea to regain for a short interval part of its old domain.

The Woodston, Orton Waterville, West Wittering, Clacton, and probably the Ilford deposits, all show freshwater beds succeeded by estuarine. Possibly the remaining localities were too far inland to show marine influence.

The Clacton deposit is thus later than the older brick-earths of Grays, and older than the Crayford deposits, and may well be termed Mid-Pleistocene.

As to the climate, this must have been very similar to that of the present day, though possibly rather more genial.

Discussion on the two foregoing Papers.

Prof. W. J. Sollas complimented the Author on the importance of his discoveries, and remarked that Essex, as represented by Mr. Reid Moir and the Author, was doing much to remove the reproach which might at one time have been made against British geologists of being rather behindhand in these matters.

The beautiful Chellean implement, with its dagger-like blade, evidently marked a different horizon from that of the overlying gravels which yielded a 'cold' fauna. The discovery of greatest importance would appear to be the presence of alleged Mesvinian implements beneath a late Acheulean horizon. These implements are good examples of the Mousterian industry, and recall the 'warm' Mousterian implements of Commont, which similarly occur in an anomalous position.

Since the 'Mesvinian' of M. Rutot was originally regarded as pre-Chellean, it might be better to restrict the use of that term to Belgium, although there also the horizon, as shown by Commont, seemed to be Acheulean. The technique of the Essex implements is, however, markedly superior to that of the Mesvinian, and they might be described as Mousterian implements on a possibly Mesvinian horizon.

The replacement of the Acheulean by Mesvinian in Belgium and the re-appearance of the Acheulean in Essex after a stage of the Mousterian industry, would seem to indicate the contemporaneous existence of two races (possibly *Eoanthropus* and *Homo neandertalensis*) which, perhaps under the influence of climatic changes, encroached on each other's hunting-grounds.

Mr. W. Whitaker said that the geological survey of the Clacton district was carried out, under his supervision, about half a century ago. Personally, he mapped only the less interesting tract east of Clacton; while the more interesting beds west of Clacton were carefully noted by Mr. W. H. Dalton, who mapped that part. The work having been done so long ago, it was clearly time that the district should be again examined, and fresh sections

noticed, and he hoped that the Author would continue his work there. Coast-sections were liable to change, and needed constant observation.

He was glad to note Mrs. Reid's remarks as to the relations of the Clacton deposit with the Forest-Bed of the Norfolk coast. On stratigraphical grounds he held that the latter was the older, and it was satisfactory that in this case stratigraphy and palæobotany were in agreement.

Mr. W. Johnson suggested that, in view of the general character of the fauna and flora of the Lea-Valley deposits, boreal would be a better term than Arctic, and that the latter term might be reserved as an equivalent for Glacial. Where did the Author place the dividing-line between the Pleistocene and the Holocene? Was the presence of the Mammoth deemed sufficient to class a deposit as Pleistocene? He thought that the Admiralty section at Spring Gardens might be considered as marking the commencement of a cold period, which lasted throughout the time when the buried channel was eroded, and during the infilling of the greater portion of that channel, the Ponders End deposit coming near the close. After the Ponders End deposit came further slight subsidences, indicated perhaps by the Hackney-Wick section. With respect to the Mesvinian implements, they seemed to represent types which are found in several periods, and, unless associated as a group, they would require further investigation before the date assigned could be accepted.

Dr. R. L. Sherlock mentioned that recently he had mapped a considerable area of clay at Cheshunt, in the Lea Valley. The clay, which appeared to be within the flood-plain terrace, was in part blue and in part black, the latter burning white as if the blackness were caused by organic matter. Unfortunately, only a very poor section had been seen, as the outcrop was built over, and evidence was obtainable solely from well-records.

The clay, which has not yielded fossils, is usually from 2 to 3 feet thick, although in one case there was over 14 feet of it. He asked the Author whether this clay was likely to be the Arctic Bed of Ponders End.

Mr. G. W. Lamplugh asked whether the Author had found any evidence bearing on the relationship of the Clacton and Ponders-End deposits to the products of the great glaciation which were recognizable a little farther north.

Prof. P. G. H. Boswell said that, according to the plant-remains, the Clacton deposits were to be correlated rather with those of Selsey than with the Cromer Forest-Bed, whereas the mammalian remains seemed to recall the Cromer Forest-Bed. It was indubitable that the Cromer Forest-Bed was earlier than the first great till of the East of England.

The Author thanked the Fellows for their favourable reception of his paper. He was glad that Prof. Sollas agreed with the Mousterian affinities of the flint-industry, which however, as a whole, was much more primitive than a true Mousterian industry,

such as that of the Stoke Newington 'floor'. But it exactly filled the place of a precursor of that industry.

In reply to Mr. Johnson, he agreed that the climate of the Arctic Bed was not an extreme Arctic one. It was always difficult to draw sharp boundaries, but he thought that all British deposits yielding contemporary Elephant and Rhinoceros should be classed as Pleistocene. He was a little puzzled by the Admiralty section; and would like to re-examine it in the light of the comparative evidence now available.

He thought it extremely probable that the clay in the flood-plain gravel referred to by Dr. Sherlock represented the same Arctic Bed; but it would, of course, need examination.

In reply to Mr. Lamplugh's question, he had not found any direct evidence of the relation of the Clacton bed to the Glacial deposits; but the higher-terrace gravels with Chellean implements contained erratics probably derived from the Boulder Clay, while the Clacton bed occupied a tributary channel which was trenched through the plain of that higher terrace.

With reference to the question raised by Prof. Boswell, the mammalia of the Clacton bed were very different from those of the Forest-Bed; in the Author's opinion, *Elephas meridionalis*, *Rhinoceros etruscus*, and their associates, which characterize the Forest-Bed, were definitely pre-Chellean.

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